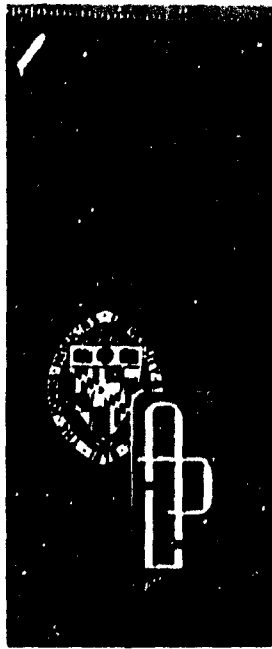


TG-864

FEBRUARY 1967

Copy No. 8



AD 654446

Technical Memorandum

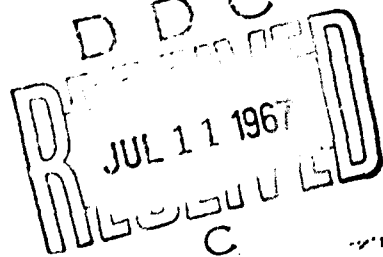
**AIRCRAFT TRACTOR
ROCKET-ESCAPE SYSTEM-
SIX-DEGREE-OF-FREEDOM
DIGITAL SIMULATION
Final Report**

by FRANK BADER and DEAN R. COLEMAN

THE JOHNS HOPKINS UNIVERSITY • APPLIED PHYSICS LABORATORY

Distribution of this document is unlimited

ARCHIVE COPY



TG-864

FEBRUARY 1967

Technical Memorandum

**AIRCRAFT TRACTOR
ROCKET-ESCAPE SYSTEM-
SIX-DEGREE-OF-FREEDOM
DIGITAL SIMULATION
Final Report**

by FRANK BADER and DEAN R. COLEMAN

THE JOHNS HOPKINS UNIVERSITY • APPLIED PHYSICS LABORATORY
8621 Georgia Avenue, Silver Spring, Maryland 20910

Operating under Contract N0w 62-0604-c, Bureau of Naval Weapons, Department of the Navy

ABSTRACT

This report presents a six-degree-of-freedom digital simulation of an aircraft tractor-rocket air crew escape system. The simulation described herein is a six-degree-of-freedom simulation in that each of the objects considered is free to translate linearly in three directions and rotate about these three linear axes. The simulation considers the motions of the four "objects" comprising the escape system: the airplane, the tractor rocket, the towline, and the crewman. The simulation begins at the instant the tractor rocket has been ejected from its catapult and terminates when the tractor rocket has burned out.

Previous simulations studied at the Applied Physics Laboratory were two-dimensional, three-degree-of-freedom digital simulations. These simulations did not reproduce the effects of aircraft out-of-control motions.

The tractor rocket escape system was conceived by the Stanley Aircraft Corporation for military aircraft which currently have no ejection systems for the air crew.

TABLE OF CONTENTS

List of Illustrations	vii
I. SUMMARY	1
II. INTRODUCTION.	3
III. DESCRIPTION OF THE SIMULATION	5
IV. PARAMETERS CHARACTERIZING SYSTEM	9
Airplane	9
Ejection Seat Parameters	10
Rocket Characteristics	10
Towline Characteristics	11
Crewman Characteristics	11
V. RESULTS PROVIDED BY THE SIMULATION	13
Values of Significant Parameters Used in the Simulation Study.	15
VI. DISCUSSION OF RESULTS	17
References	61

LIST OF ILLUSTRATIONS

Figure		Page
1	Test of Tractor Rocket Escape System	21
2	Aircraft Flight Simulation Condition Nos. 1, 22, and 23	22
3	Aircraft Flight Simulation Conditions Nos. 2 through 5, 24, and 25	23
4	Aircraft Flight Simulation Conditions Nos. 8 through 11	24
5	Aircraft Flight Simulation Conditions Nos. 12 through 16	25
6	Aircraft Flight Simulation Condition No. 17	26
7	Aircraft Flight Simulation Condition No. 18	27
8	Aircraft Flight Simulation Condition No. 19	28
9	Aircraft Flight Simulation Conditions Nos. 20 and 21	29
10	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 1	30
11	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 2	31
12	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 3	32
13	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 4	33
14	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 5	34
15	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 8	35

LIST OF ILLUSTRATIONS (Cont'd)

Figure		Page
30	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 23 . .	50
31	Simulated Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 24 . .	51
32	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 25 . .	52
33	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 1b (Rocket Catapulted 27° ahead of Vertical) . .	53
34	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 2b (Rocket Catapulted 27° ahead of Vertical) . .	54
35	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 3b (Rocket Catapulted 27° ahead of Vertical) . .	55
36	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 4b (Rocket Catapulted 27° ahead of Vertical) . .	56
37	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 5b (Rocket Catapulted 27° ahead of Vertical) . .	57
38	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 8b (Rocket Catapulted 27° ahead of Vertical) . .	58
39	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 9b (Rocket Catapulted 27° ahead of Vertical) . .	59
40	Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 10b (Rocket Catapulted 27° ahead of Vertical) . .	60

I. SUMMARY

The Naval Air Systems Command authorized the Applied Physics Laboratory (Ref. 1) to perform a six-degree-of-freedom digital computer simulation analysis of the Stanley Aviation Corporation's "Yankee" tractor rocket aircrew escape system, see Fig. 1.* Because this escape system proposes to extract crewmen from out-of-control (spinning) aircraft, NAVAIRSYSCOM further requested, via Ref. 1, that APL use aircraft spin data from Ref. 2 in its studies. Twenty five specific sample intervals were specified by the Naval Air Systems Command from this data for evaluation through a computer analysis.

The ejection simulation study for 23 of these flight conditions has been completed. NATC data in Ref. 2 were incomplete for two of the runs (aircraft pitch angle missing), so these were omitted from the analysis. The aircraft flight conditions for the 23 data samples are summarized in Figs. 2 through 9. The simulation results are shown in Figs. 10 through 33. Each of these figures shows five plot systems which collectively indicate the following quantities for each simulated ejection.

1. The crewman's and rocket's ejection trajectory with respect to a coordinate system attached to the maneuvering aircraft.
2. The magnitude and direction of the forces exerted upon the crewman during ejection, relative to a coordinate system moving/rotating with him.

* All illustrations may be found in the back of this report beginning on page 21.

In eight additional runs, the rocket catapult angle was 63° instead of 77° (corresponding to an earlier Stanley design); simulation results for these runs appear in Fig. 33 through 40. These illustrations graphically represent APL simulation findings for flight conditions originally specified by the NAVAIRSYSCOM task, and additionally, eight runs that duplicate aircraft maneuvers of eight of those specified, but use a changed value for one parameter in the ejection system; namely the tractor rocket launch angle. As will be seen later, this duplication affords a valuable basis for comparison of ejection system constants, suggesting an optimal compromise for angle for rocket launch.

In general, the simulation study showed that the tractor rocket escape system could successfully remove a crewman from a maneuvering aircraft provided aircraft roll/pitch rates were not excessive (i. e. , were below $100^\circ/\text{second}$).

The 67° rocket launch angle produced more ejection failures than the 77° value since it augmented the angle of pull between the tractor rocket and the crewman in the rolling airplane.

II. INTRODUCTION

The Stanley Aviation Corporation has proposed the use of a tractor rocket operated aircrew escape system called "Yankee" for removal of aircrewmembers faced with the need for bailout. This system appears to have certain advantages and limitations different from the aircraft ejection seats currently in use.

The tractor rocket escape system conceived by Stanley Aviation provides for the extraction of a crewman from an aircraft according to the following sequence, most simply pictured (see Fig. 1) for a non-maneuvering aircraft flying at a slow speed.

1. A rocket located under the aircraft canopy aft and above the cockpit is catapulted from the aircraft at a preset attitude.
2. The rocket deploys a 10-foot towline whose other end is attached to the crewman's parachute harness. The rocket ignites when the entire length of the towline has been deployed and for 0.5 second thereafter exerts a 2000-pound pull upon the crewman in a roughly vertical direction, (along his longitudinal axes). This pull will extract him from the cockpit about 0.2 second from rocket ignition time, and impart to him a maximum upward speed over 100 ft/sec. The coupled system of rocket-towline-crewman tends to align itself in a straight line as it departs from the aircraft.

Ejection dynamics become more complex in direct proportion to the complexity of the aircraft motion. Linear and rotational aircraft motion can compromise the crewman's safe extraction through either of these two mechanisms:

1. From aerodynamic drag upon the components of the ejection system (rocket-rope-crewman) which increase with augmentation of the aircraft forward speed, tending to carry the rocket out of the cockpit during the 1/3-second time interval required for rocket deployment and crewman extraction. This, in turn, will produce a rearward trajectory for the escaping crewman.
2. From aircraft rotation during the time interval from catapulting of the tractor rocket to the instant of emergence of the crewman. Such rotation causes an increase in the angle of misalignment of pull upon the crewman equal to the aircraft rotation during this time interval.

Both of these effects may occur in random combinations, particularly when the aircraft is out of control. The first, flight speed, has a more systematic effect than the latter, and may be partially mitigated by adjusting the rocket launch angle more forward of vertical for ejection at higher aircraft speeds. (For aircraft speeds up to 340 knots, a single fixed forward "tilt" angle around 15° may suffice.) The second of these effects, aircraft rotation, presents major difficulties for any approach at compensation. Theoretically, a variable-angle rocket launcher, servo controlled from roll/pitch rates, might effect such a compensation, but only at the price of excessive system complexity.

III. DESCRIPTION OF THE SIMULATION

The simulation described here is a six-degree-of-freedom simulation in that each of the objects considered is free to translate linearly in three directions and rotate about these three linear axes. The simulation considers the motions of the four "objects" comprising the escape system: the airplane, the tractor rocket, the towline, and the crewman. The simulation begins at the instant the tractor rocket has been ejected from its catapult and terminates when the tractor rocket has burned out (or the crewman can be "coasted" up to maximum altitude). Subsequent parachute deployment is not simulated.

The simulation problem proper is solved principally in an earth-bound rectangular coordinate system where the aircraft is initially positioned at a specified altitude above the origin. The aircraft possesses an arbitrary velocity along each coordinate axis and an arbitrary pitch/yaw/roll attitude. Subsequent aircraft motion is derived by entering linear acceleration and angular velocity data into the calculation at each 0.1-second time increment and then employing these values as constants during the succeeding 0.1-second interval. Linear accelerations and velocities are integrated to produce positions; the aircraft attitude is determined by space projection, after rotation, of a set of unit vectors affixed to the aircraft.

The rocket trajectory is found by computing towline, aerodynamic, and gravity forces and their moments upon it, deriving its linear and angular accelerations through Newton's laws of motion, and integrating

accelerations into velocities and position. The rocket angular accelerations are derived in a rocket-based coordinate system in order to cope with the asymmetry of the rocket's moments of inertia. The rocket space attitude is found through rotation of a set of unit vectors in the rocket system, which is then projected on the ground plane.

As a distributed system, the towline is treated in an approximate fashion. In principle, since the forces exerted on the towline by wind drag are distributed along its length, the line will possess a curve along its length. The stretched length of the line, and hence its tension, are then a function of both the distance between its ends (tie points to rocket and crewman) and the wind deflection. Typically, the towline tension force caused by rocket pull is around 2000 pounds, and is very large compared to crosswind forces; therefore, in this simulation, the simplification is made that the towline forces are computed as if the line were straight between its two ends. These forces are a longitudinal force (along the line joining the two ends of the line) proportional linearly to the stretch in line length and a wind force perpendicular to the line and in the direction of the crosswind. The tension force and half of the cross-wind force are applied to man and to the rocket.

The crewman is treated as a rigid body of rectangular form possessing three mutually perpendicular drag areas and three given moments of inertia. The crewman's motion is confined to the seat back track axis until he emerges from the aircraft. Applied forces are resolved perpendicular and parallel to this axis. Perpendicular ones are assumed to create a proportional frictional force which is subtracted from the tangent

force. Using these forces, the crewman's space acceleration is computed along the seat back axis and used to compute his acceleration relative to the aircraft. During this period the crewman's attitude is constrained to remain fixed with respect to the aircraft and its rotation. The crewman's location with respect to the aircraft is then secured by (double) integration of his relative acceleration. After the crewman has traveled far enough to emerge from the aircraft, the aircraft constraints are removed and his body, initially oriented along the seat back axis and rotating with it, is now free to rotate and translate in six degrees of freedom. The crewman's subsequent linear and angular accelerations are computed from the subsequent linear and angular accelerations are computed from the applied forces (aerodynamic, line, and gravity) and their moments. The crewman is assumed to remain rigid and to be symmetrical with respect to aerodynamic forces. The crewman's position and attitude are then computed in a manner analogous to that described in connection with the rocket. No tip-off torques are applied to the crewman as he emerges from the aircraft. A proper representation of these torques would require description of the crewman's body as a jointed elastic system and would require specific definition of the cockpit enclosure that originally contains him.

Once free of the aircraft, the rocket, towline, and crewman are followed as a coupled system until burnout of the tractor rocket, ignoring the aircraft. At rocket burnout, the crewman's trajectory and position are coasted with only gravity and aerodynamic forces acting. The calculation is terminated when the crewman reaches the peak altitude of his trajectory.

IV. PARAMETERS CHARACTERIZING SYSTEM

Airplane

The airplane is characterized by its position in a rectangular coordinate system in space. The origin of this coordinate system is located beneath the crewman's position in the aircraft at zero time.

PA1	the aircraft distance north of the origin	
PA2	the aircraft altitude above the origin	
PA3	the aircraft position east of the origin	
DPA1	aircraft velocity north (ft/sec)	
DPA2	aircraft velocity upward (ft/sec)	
DPA3	aircraft velocity east (ft/sec)	
DVA1	aircraft acceleration forward (ft/sec ²)	} in aircraft coordinates
DVA2	aircraft acceleration upward (ft/sec ²)	
DVA3	aircraft acceleration forward (ft/sec ²)	
THAV	aircraft attitude angle above horizontal	
THAB	aircraft attitude angle east of north	
THAR	aircraft roll angle to right of vertical	
WA1	aircraft roll rate	} in aircraft coordinates
WA2	aircraft yaw rate	
WA3	aircraft pitch rate	

Initial values for aircraft position, PA2, PA3, velocity DPA1-3, attitude angles THAV, THAB, and THAR are taken from Patuxent Naval Air Test Center flight test data and entered into the simulation. Successive aircraft positions are generated through read-in of aircraft linear acceleration and angular velocity data. These are used to increment the aircraft

velocity/position and to rotate the aircraft coordinate system to reproduce in the simulation the actual aircraft motions described in the Patuxent NATC test report.

Ejection Seat Parameters

GAMM	the seat back track angle guiding crewman's exit from aircraft
THARV	the rocket launcher elevation angle
THARB	the rocket launcher bearing angle
HTSTR	height of aircraft fuselage structure above crewman's center of mass seated in cockpit
CFR1C	coefficient of friction of crewman's seat on track
DR(1)	rocket position in aircraft, fore/aft of crewman
DR(2)	rocket position in aircraft, above crewman
VRL	launch velocity of rocket catapult (ft/sec)
WRO	rocket spin rate
XLM1	distance forward from crewman's CG to towline harness
XLM2	distance up from crewman's CG to towline harness
XLR	distance from rocket CG to towline tie point

Rocket Characteristics

TBR	duration of rocket burning (seconds)
TDB	time of rocket ignition delay from towline deployment (seconds)
TRF	time of rocket launch to rocket ignition if time ignition is used (seconds)
TTB	time constant of rocket thrust build up (seconds)
TTD	time constant of rocket thrust delay (seconds)
WTR	mass of rocket initially (slugs)

DWTR	rate of burning of rocket propellant (slugs/sec)
XJR1	rocket moments of inertia about principal axes
XJR2	
XJR3	
IJTMAX	maximum rocket thrust (pounds)
ACDR1	rocket drag areas
ACDR2	
ACDR3	
RL	rocket length

Towline Characteristics

TL	length of towline (feet)
DROPE	effective line diameter
WROPE	mass of line
CROPE	drag coefficient of line
TBYO	initial payout drag on line
TBYD	rate of increase of rope payout force with line length extended
TKL	elastic rope force stretch constant of line (pounds force/foot stretch)
TVL	rope internal friction damping coefficient (pounds force/foot/sec stretch rate)

Crewman Characteristics

WTM	mass of crewman, with equipment
XJM1	man's moment of inertia about three principal body axes
XJM2	
XJM3	

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
SILVER SPRING MARYLAND

ACDM1 }
ACDM2 } man's aero drag areas about three principal axes
ACDM3 }
HMH distance man's center of mass to head
HMF distance man's center of mass to feet
HMA distance from man's center of mass to center of
aerodynamic pressure

V. RESULTS PROVIDED BY THE SIMULATION

The digital computer program provides as outputs the following quantities.

T	time in ejection cycle
PA1 } PA2 } PA3 }	aircraft space position north, above the east of origin
DPA1 } DPA2 } DPA3 }	aircraft speed in space north, upward and eastward
THAV	aircraft pitch attitude
THAB	aircraft heading
THAR	aircraft bank angle
WA1 } WA2 } WA3 }	aircraft axis forward, up, and right
TL	towline length
PR1 } PR2 } PR3 }	tractor rocket position same inertial (earthbound) coordinate system as for airplane
DPR1 } DPR2 } DPR3 }	tractor rocket velocity, coordinates as above
THRV	rocket attitude angle
THRB	rocket heading angle

WR1	}	tractor rocket angular velocity about three fixed inertial axes
WR2		
WR3		
PM1	}	crewman's space position, same inertial (earthbound) coordinate system as for airplane
PM2		
PM3		
DPM1		
DPM2		crewman's space velocity, same inertial coordinates as position
DPM3		
WM1		
WM2	}	crewman's angular velocity about earth located inertial axes
WM3		
AMA1	}	crewman's position with respect to aircraft, first coordinate is forward along fuselage, second up in respect to cockpit, and the third out along the right aircraft wing; this coordinate system is affixed to the aircraft and rotates/translated with it.
AMA2		
AMA3		
GMM1	}	accelerations applied to the crewman, g's (applied force divided by crewman's weight) along crewman's three axes; first axis is forward of crewman, second is foot-to-head, and third is along crewman's left-right; this coordinate system rotates with the man
GMM2		
GMM3		
GEES		total acceleration applied to crewman
GMMV		direction of total acceleration with crewman's foot-head axis
GMMB		direction of total acceleration projected into the forward/sideways plane with respect to crewman's forward direction
ARA1	}	tractor rocket location with respect to the aircraft measured in aircraft coordinates
ARA2		
ARA3		

Values of Significant Parameters Used in the Simulation Study

Towline

Length	10 feet
Diameter	2 strands 0.42 inch
Elasticity	2800 pounds force/foot (total stretch, 2 strands)
Damping	45 pounds force/foot/sec stretch rate
Payout Resistance	5 pounds force, constant during payout
Rope Drag Coefficient	1.2

Rocket

Length	2.36 feet
Towline Attach	1.2 feet aft of center of gravity
Weight	21 pounds
Burning Rate	15.5 pounds/sec
Lateral Drag Area	0.6 ft^2
End on Drag Area	0.086 ft^2
Axial Moment of Inertia	0.007 slug ft^2
Central Moment of Inertia	0.06 slug ft^2
Burning Time	0.5 second
Rocket Ignition	at towline deployment
Rocket Thrust Build-up Time	0.03 second
Rocket Maximum Thrust	2000 pounds

Crewman

Height	6 feet
Distance Head/CG	2.5 feet

Weight (including equip.)	200 pounds
Distribution - Center of Mass/ Center of Aero Press.	0.5 foot
Axial Moment of Inertia	1.5 slug ft ²
Perpendicular Moment of Inertia	8 slug ft ²
Frontal Drag Area	10 ft ²
Lateral Drag Area	7 ft ²
Head-on Drag Area	1.2 ft ²
<u>Escape System</u>	
Seat Back Angle	7° aft of vertical
Rocket Catapult angle	13° ahead of vertical
Rocket Catapult Velocity	115 ft/sec
Rocket Location	1.7 feet aft of crewman; 2.6 feet above crewman
Seat Back Friction Coefficient	0.1
Rocket Spin Rate	0.0
<u>Aircraft Parameters</u>	
Fuselage Structure above Crewman's CG in Seat Aircraft Position	7.5 feet

Velocity and maneuver data otherwise read in as selected from NATC test data.

In the event the value of any input parameter for a simulated ejection was changed, the changed value for that run will be given in the top-right hand corner of the appropriate figure. (In the case of Figs. 33 through 40 the rocket catapult angle was increased to 27° ahead of vertical.)

VI. DISCUSSION OF RESULTS

Figures 2 through 9 include a condensed representation of the A1H/J aircraft flight motions as extracted from the NATC report. The aircraft flight conditions are labeled with numbers 1 through 23, and correspond to those data samples specified by the Naval Air Systems Command for input into the ejection system simulation. Figures 10 through 32 should be referenced by their condition number, which correspond to the aircraft maneuvers as appear in Figs. 2 through 9. Figures 33 through 40, duplicating conditions 1 through 5 and 8 through 10 in the manner already described, attach the letter "b" to their condition number (i. e., 1b through 5b and 8b through 10b). These then represent the data requested by the Naval Air Systems Command. The success/failure of ejection in these runs needs to be considered on three major factors in order of decreasing significance.

1. Did the ejection system succeed in removing the crewman from the cockpit at all.
2. If ejected, did the crewman's trajectory have a suitable shape to carry him clear of the aircraft envelope.
3. Were the forces imposed upon the crewman within levels not causing severe injury.

Based upon criteria (1) and (2), all ejection simulated with the tractor rocket launched 13° ahead of the aircraft vertical were successful except for conditions 8 and 9. When the rocket was launched at 27° instead of 13° forward of vertical, a successful ejection was simulated for

condition 9 but escape failure resulted for condition 5 as well as condition 8.

Any decision as to the degree of injury the crewman would experience must be left to the judgment of specialists trained in aviation medicine and physiology. Such an evaluation might be made from the plots of forces upon the aircrewman included on each figure.

These runs were made with the specific system parameters and crewman weight indicated. In general, changes in these parameters will effect the success of escape. In particular, the following factors are noteworthy qualitative relationships that are relevant. (These are inferred from basic physical laws and not from these simulation studies.)

1. Decrease in rocket thrust will increase the time required for the crewman to escape and will, in the presence of aircraft rotation, reduce the crewman's probability of escape. Increase in rocket thrust will decrease time to emergence and hence increase allowable values of aircraft rotational rates for which escape is successful.
2. Increase of crewman's equipped weight affects the crewman's escape velocity inversely for a given rocket thrust level. This increase in crewman's weight will have an analogous effect as decrease in rocket thrust and visa-versa.
3. Increase in the forward tilt angle of the rocket catapult provides a compensation for higher forward flight speed, but for rotating aircraft at slow speeds increases the pull angle between the tractor rocket and the crewman's seat track along which he must emerge. This can be seen by

comparing crewman escape trajectories in Figs. 10 through 15 and 18 through 20 (conditions 1 through 5 and 8 through 10) with figures 33 through 40 (conditions 1b through 5b and 8b through 10b).

Prior to the present simulation project, the effects of aircraft flight speed had been studied at the Applied Physics Laboratory in a two-dimensional, three-degree-of-freedom digital simulation described in Ref. 3, but this simulation was unable to reproduce the effects of aircraft out-of-control motions. On this account the Naval Air Systems Command requested that the Applied Physics Laboratory produce a six-degree-of-freedom tractor rocket ejection escape system simulation to permit simulation of aircrew ejection trajectories from out-of-control aircraft possessing motions such as are described in the Naval Air Test Center, Patuxent, report, Ref. 2. The simulation described in this report was produced to meet this need.



Fig. 1 Test of Tractor Rocket Escape System

Best Available Copy

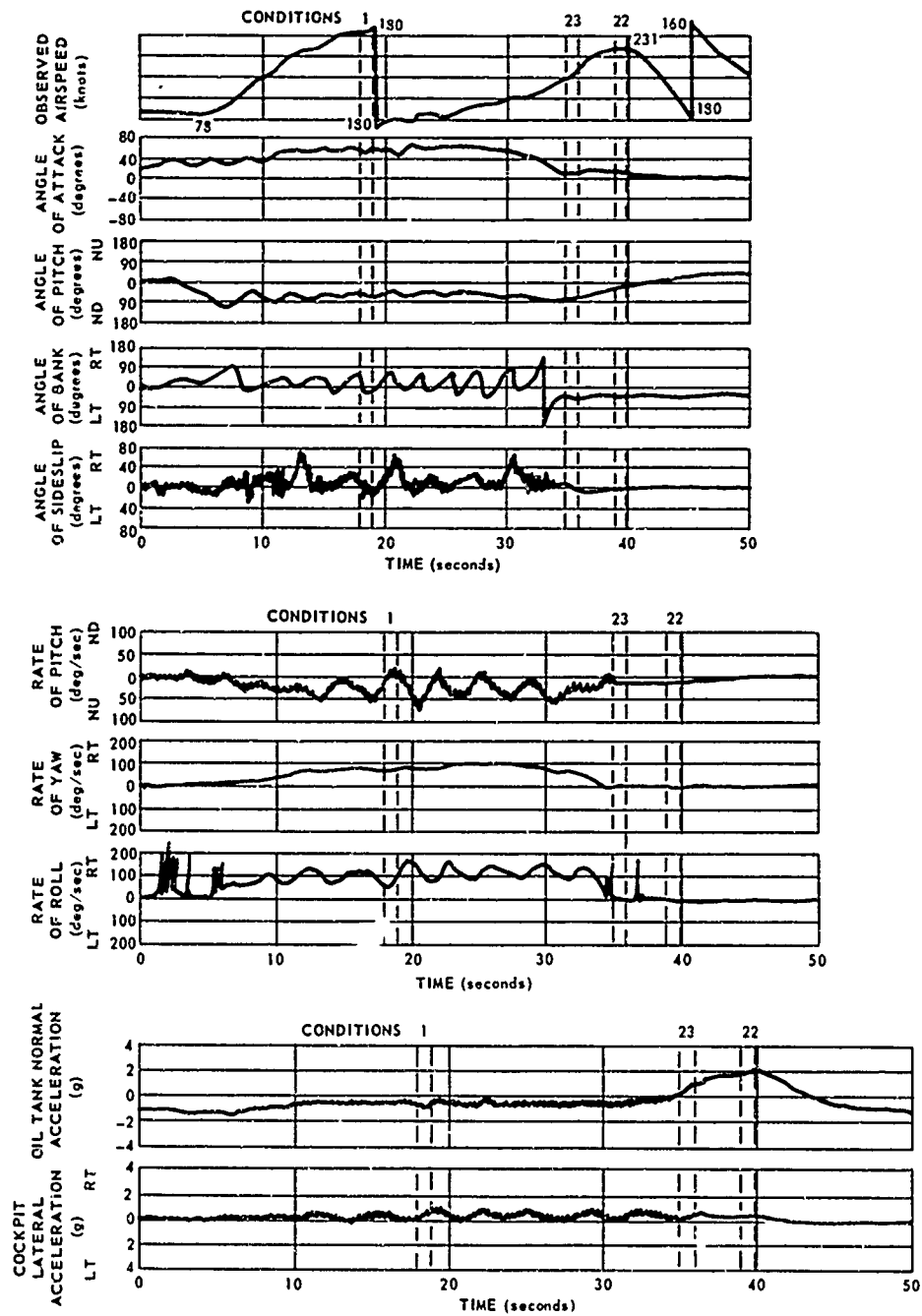


Fig. 2 Aircraft Flight Simulation Conditions Nos. 1, 22, and 23

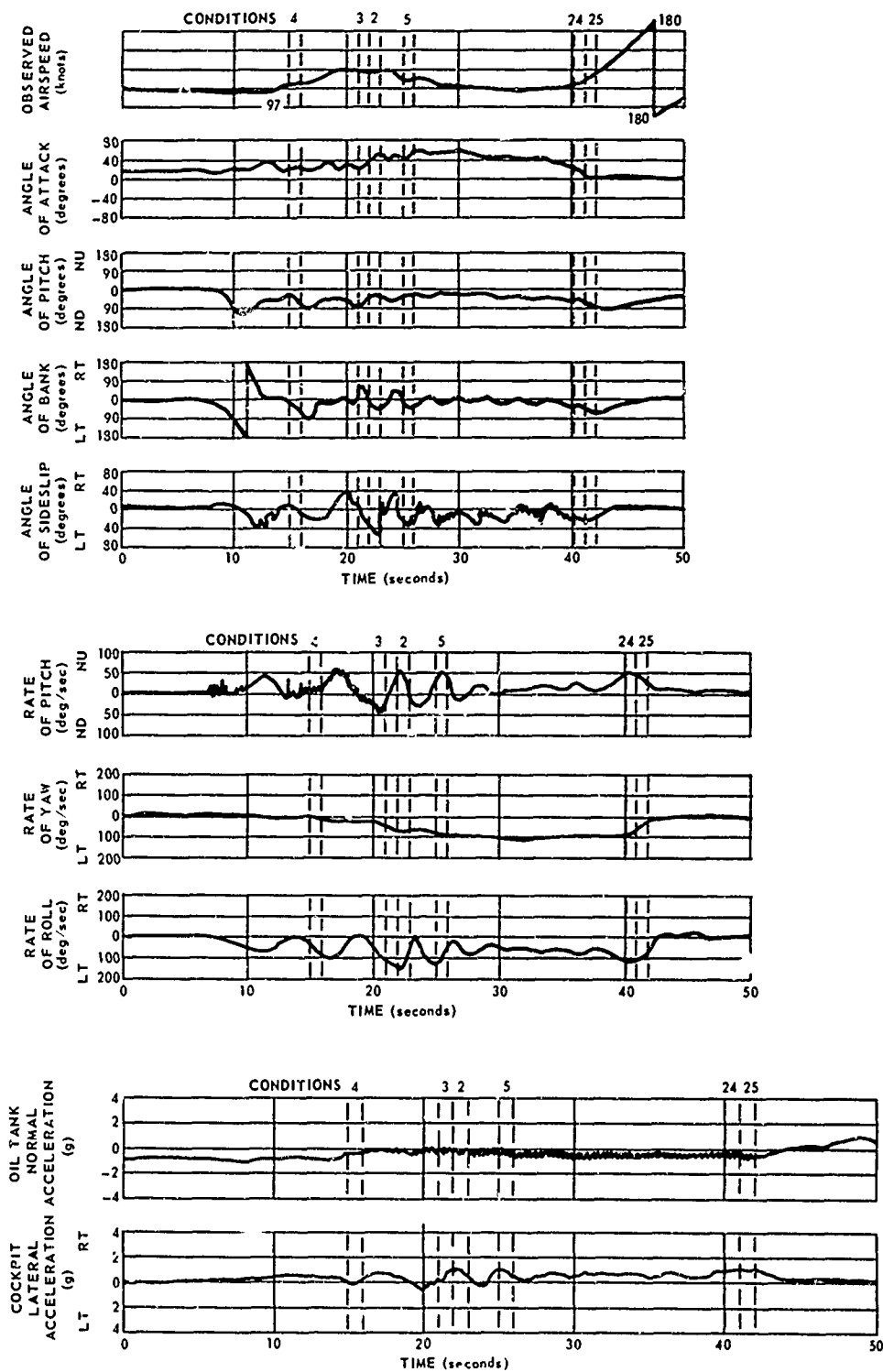


Fig. 3 Aircraft Flight Simulation Conditions Nos. 2 through 5

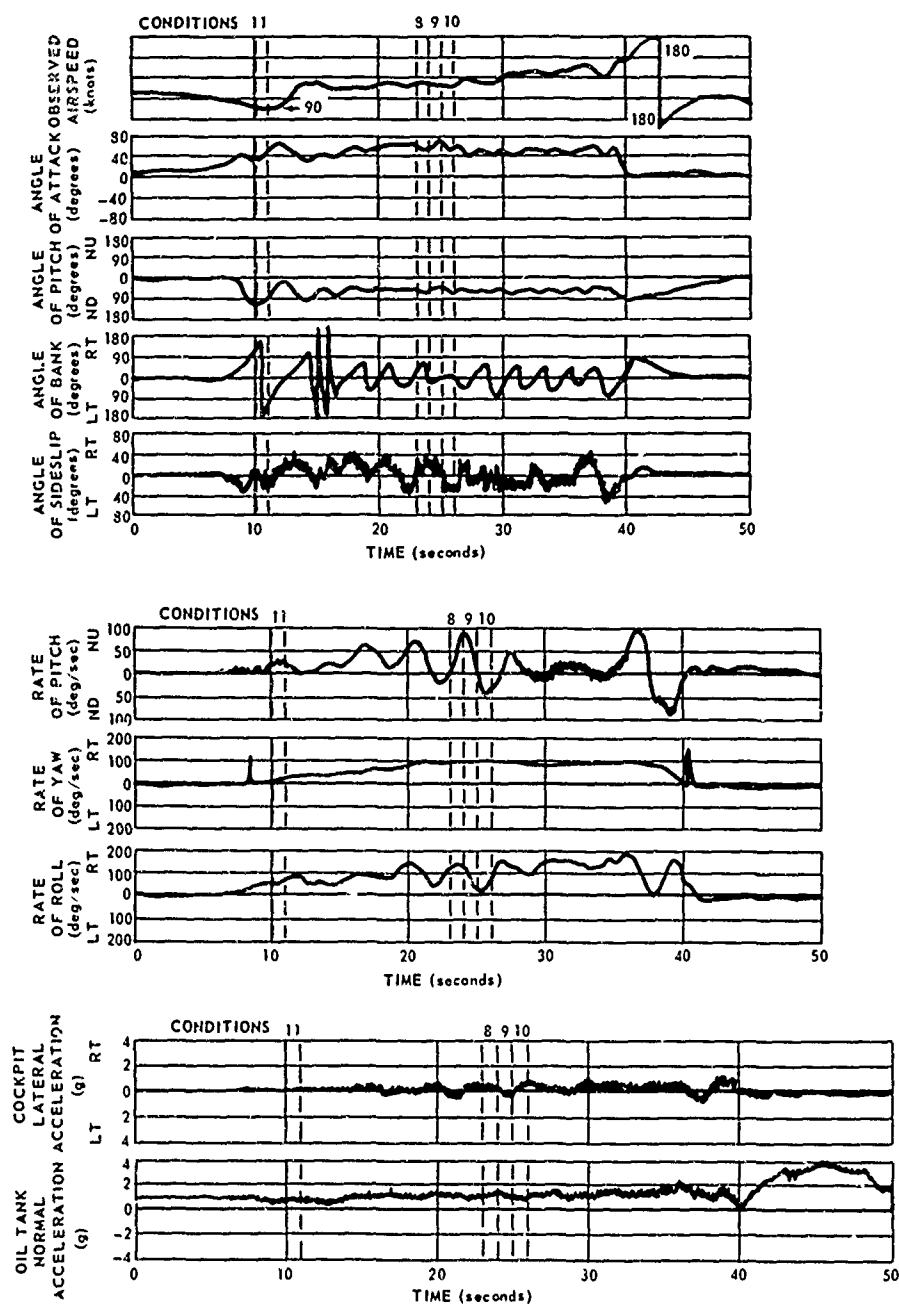


Fig. 4 Aircraft Flight Simulation Conditions Nos. 8 through 11

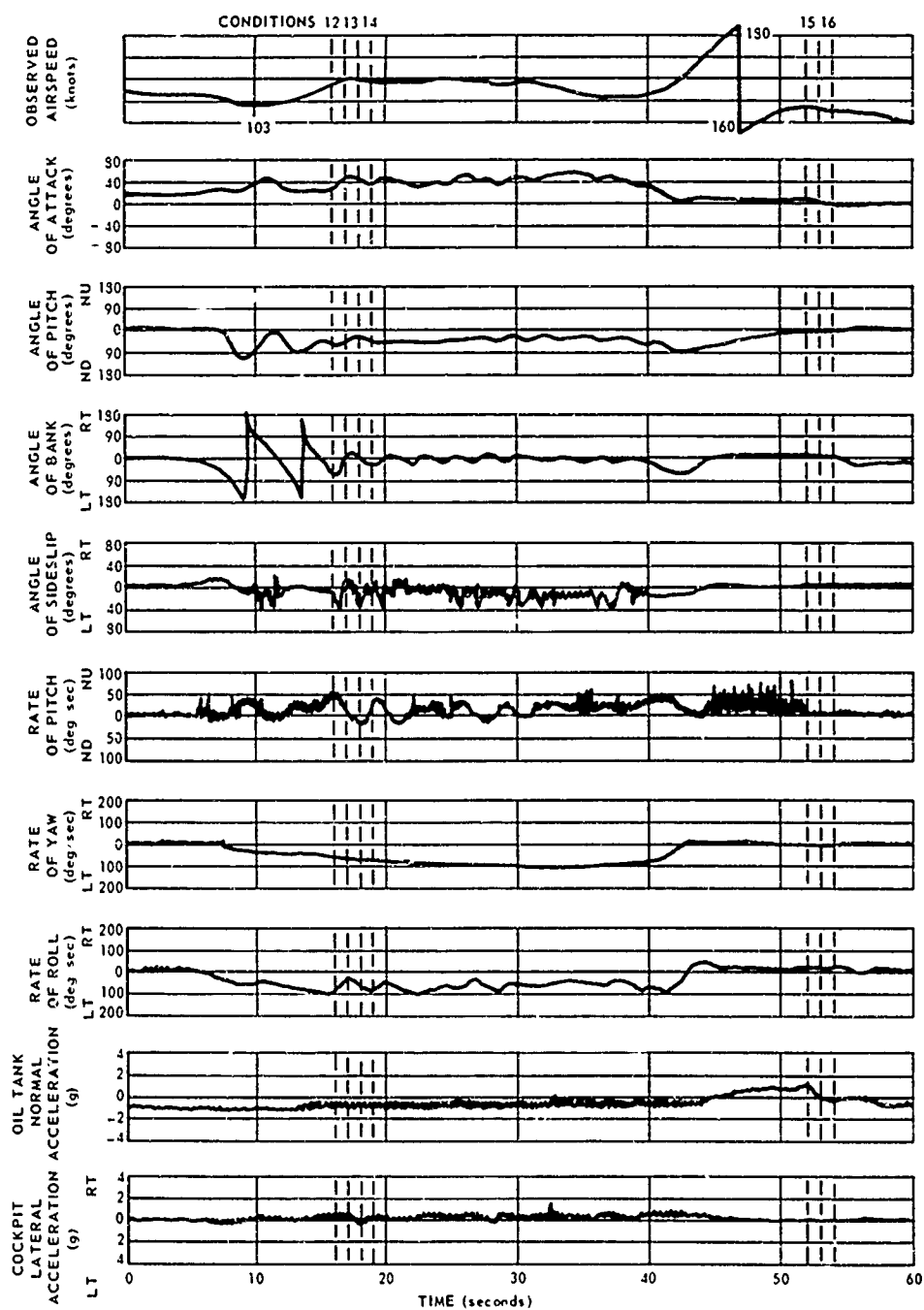


Fig. 5 Aircraft Flight Simulation Conditions Nos. 12 through 16

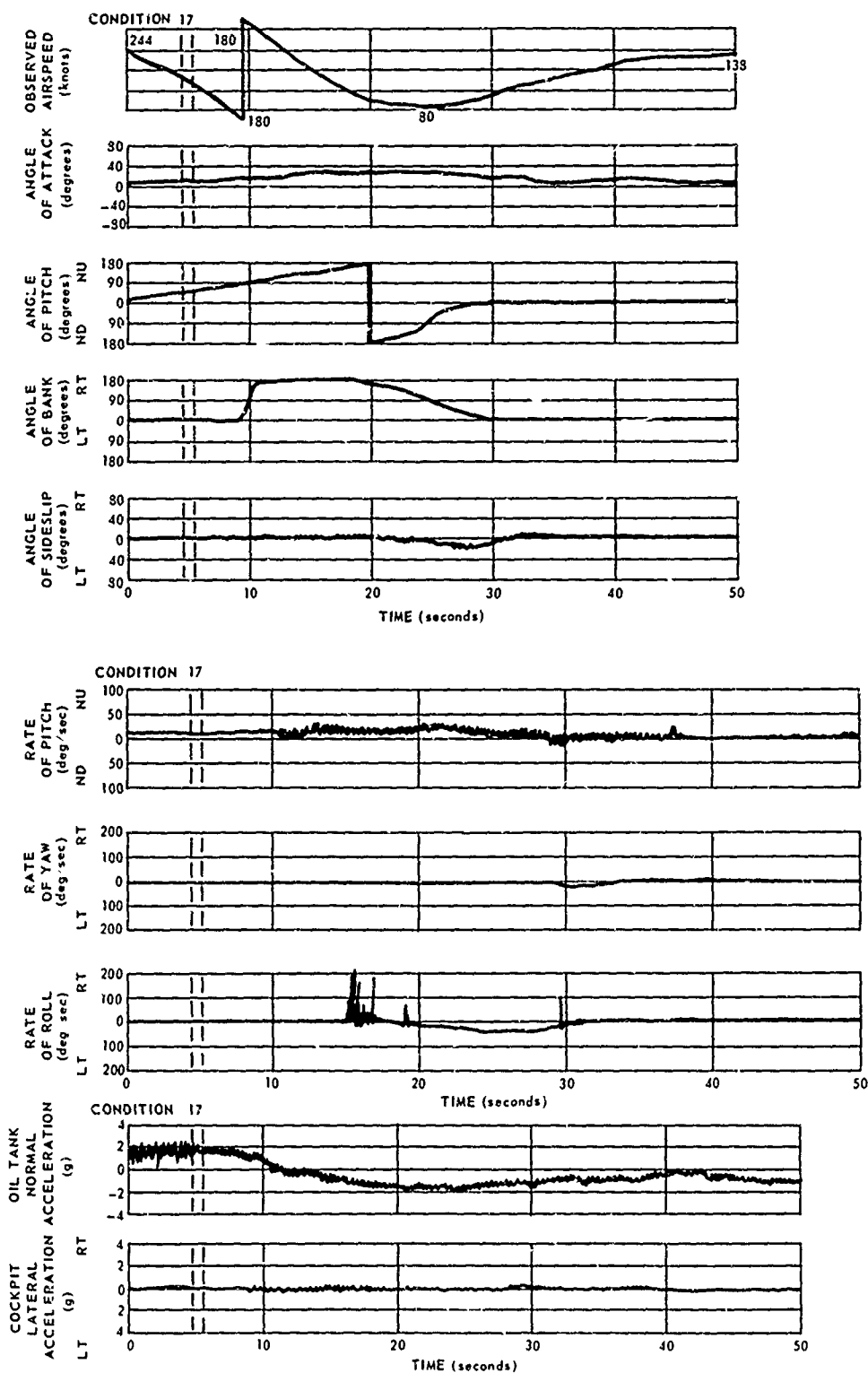


Fig. 6 Aircraft Flight Simulation Condition No. 17

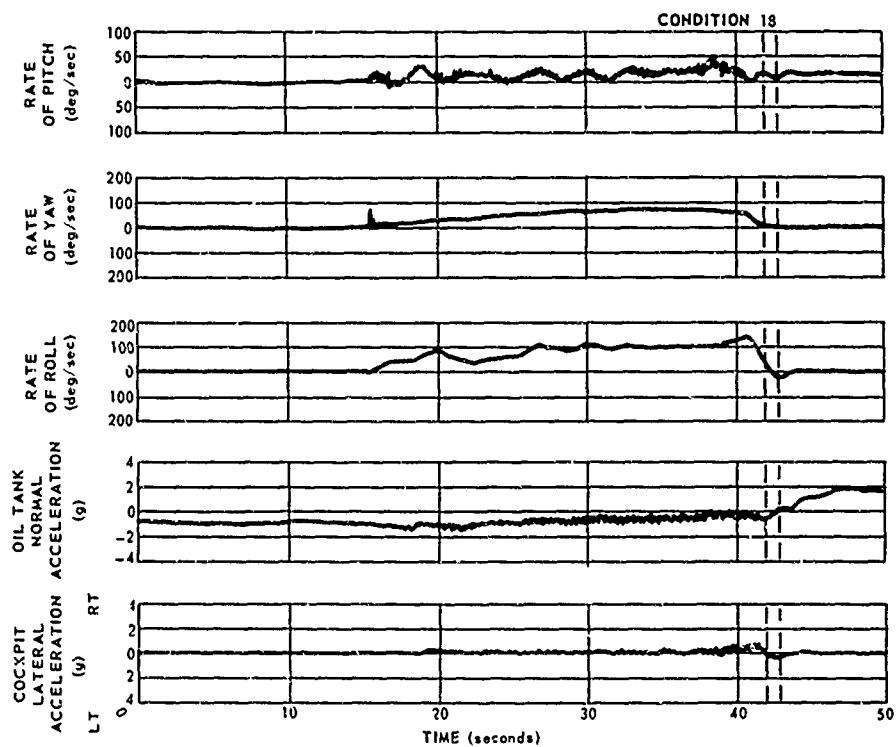
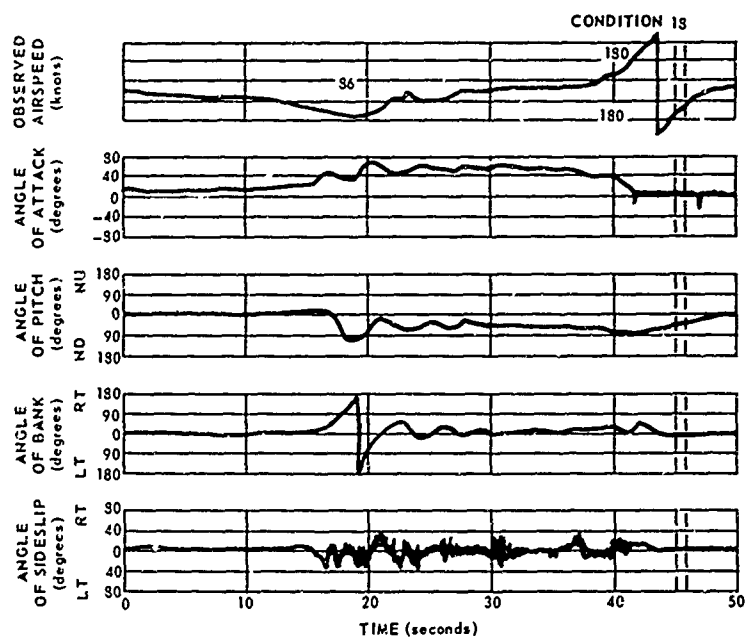


Fig. 7 Aircraft Flight Simulation Condition No. 18

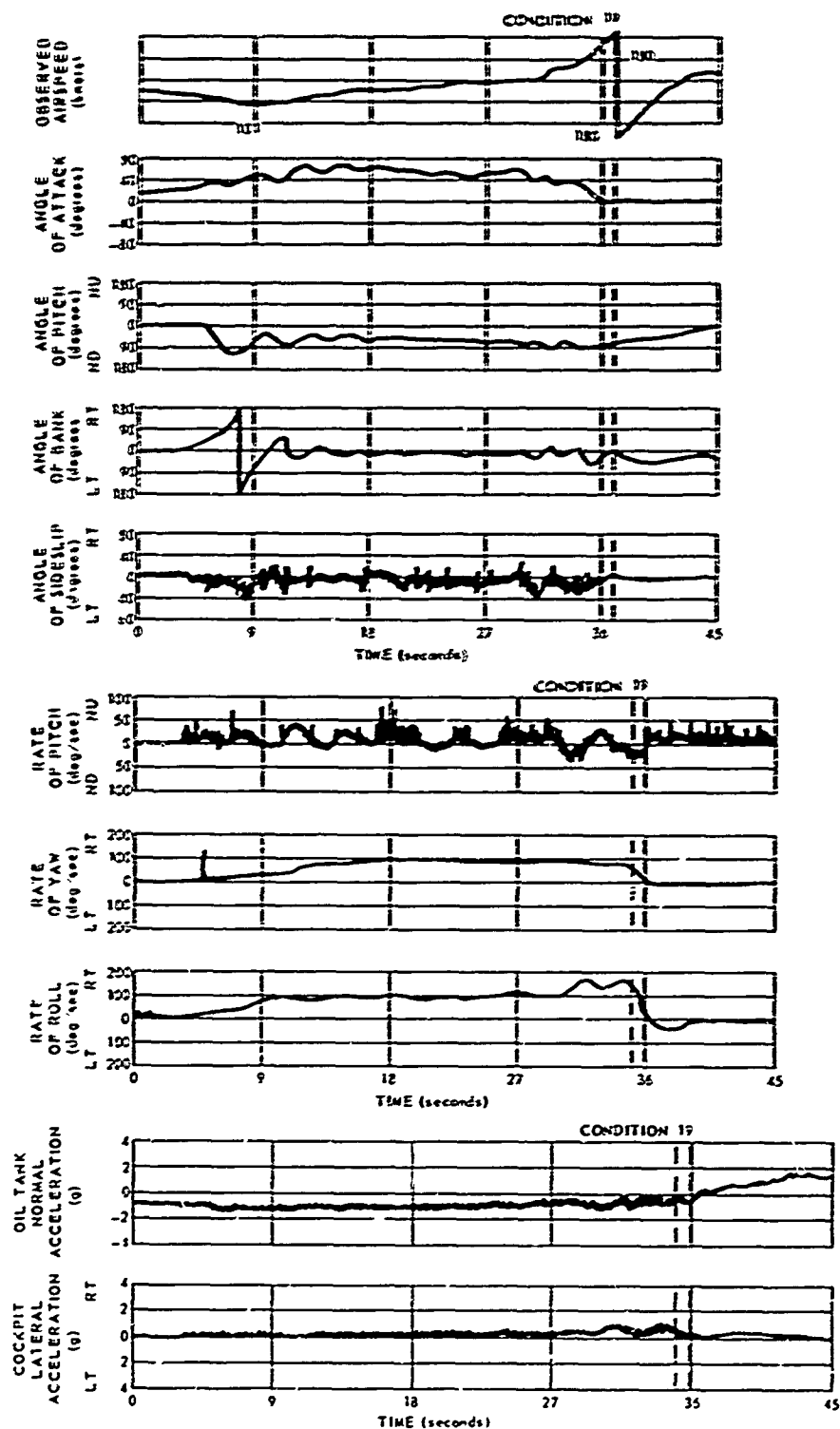


Fig. 8 Aircraft Flight Simulation Condition No. 19

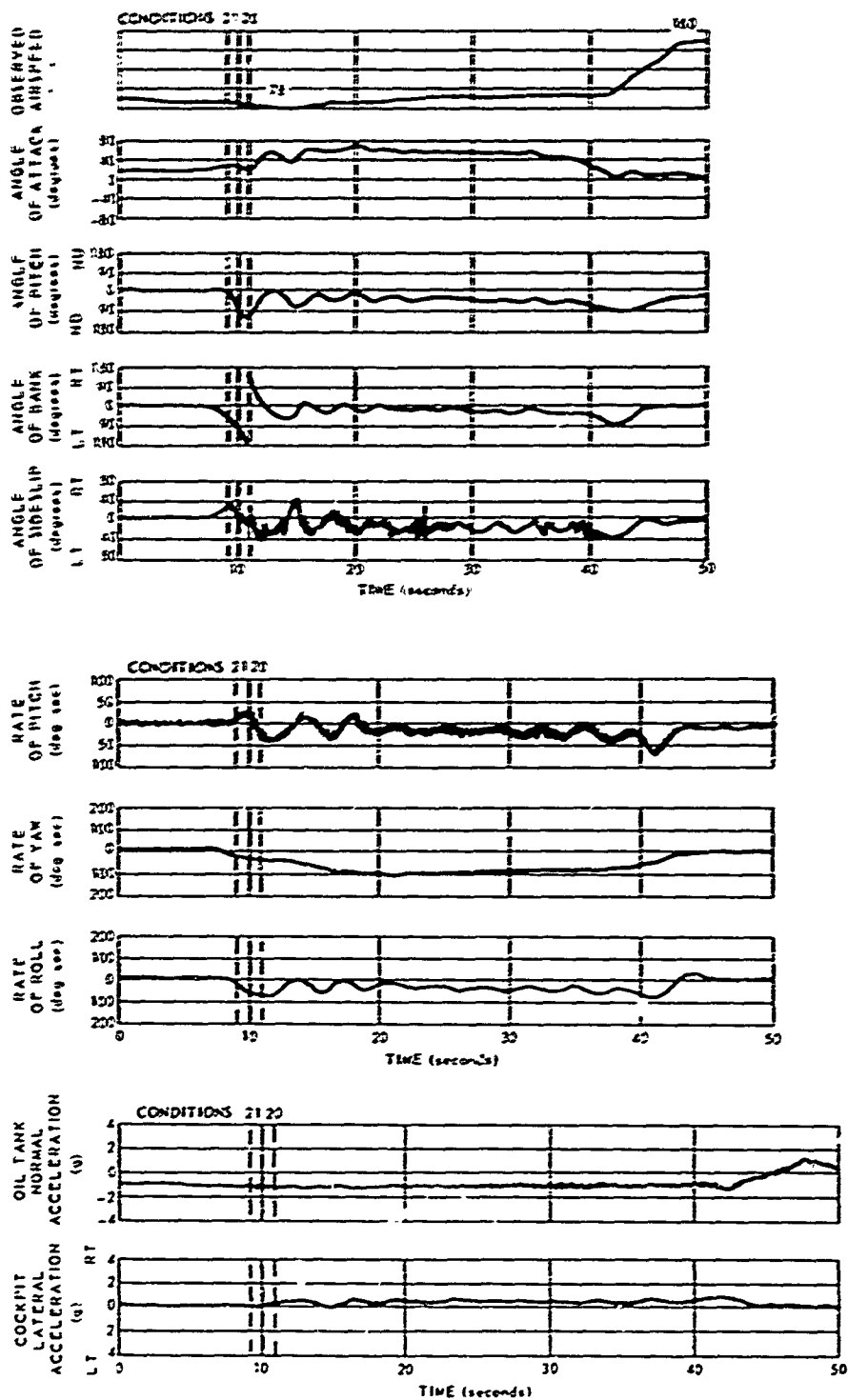


Fig. 9 Aircraft Flight Simulation Conditions Nos. 20 and 21

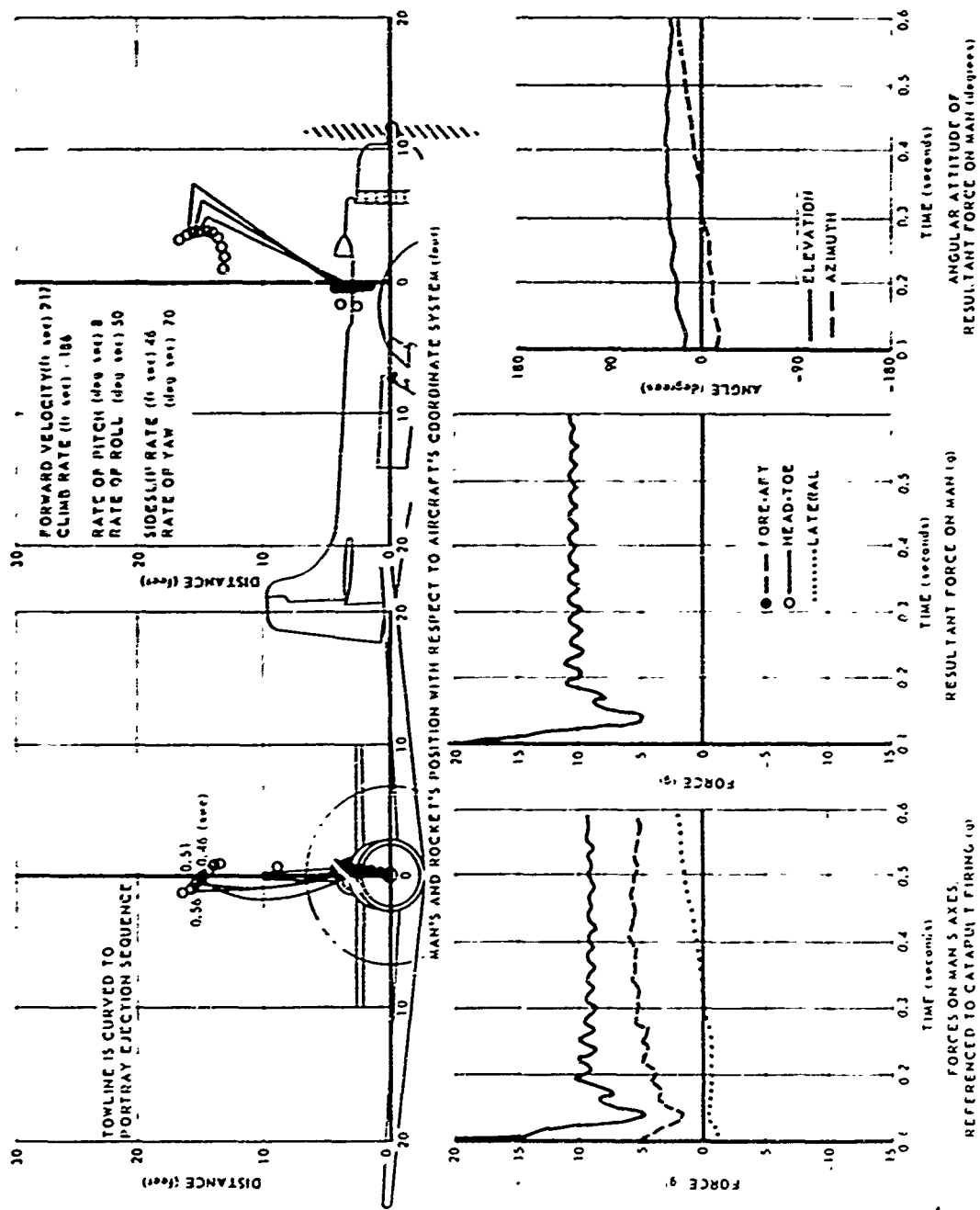


Fig. 10 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 1

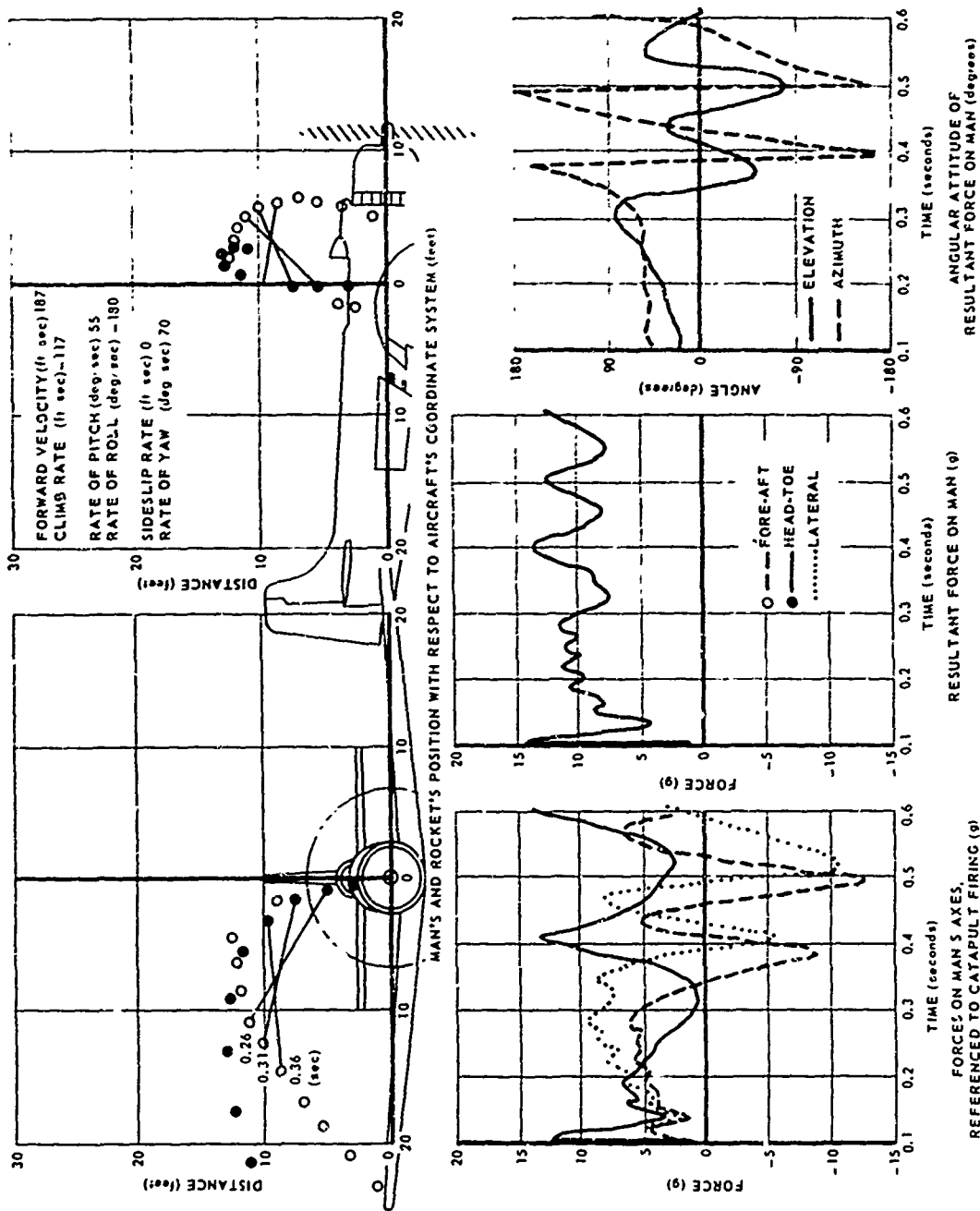


Fig. 11 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 2

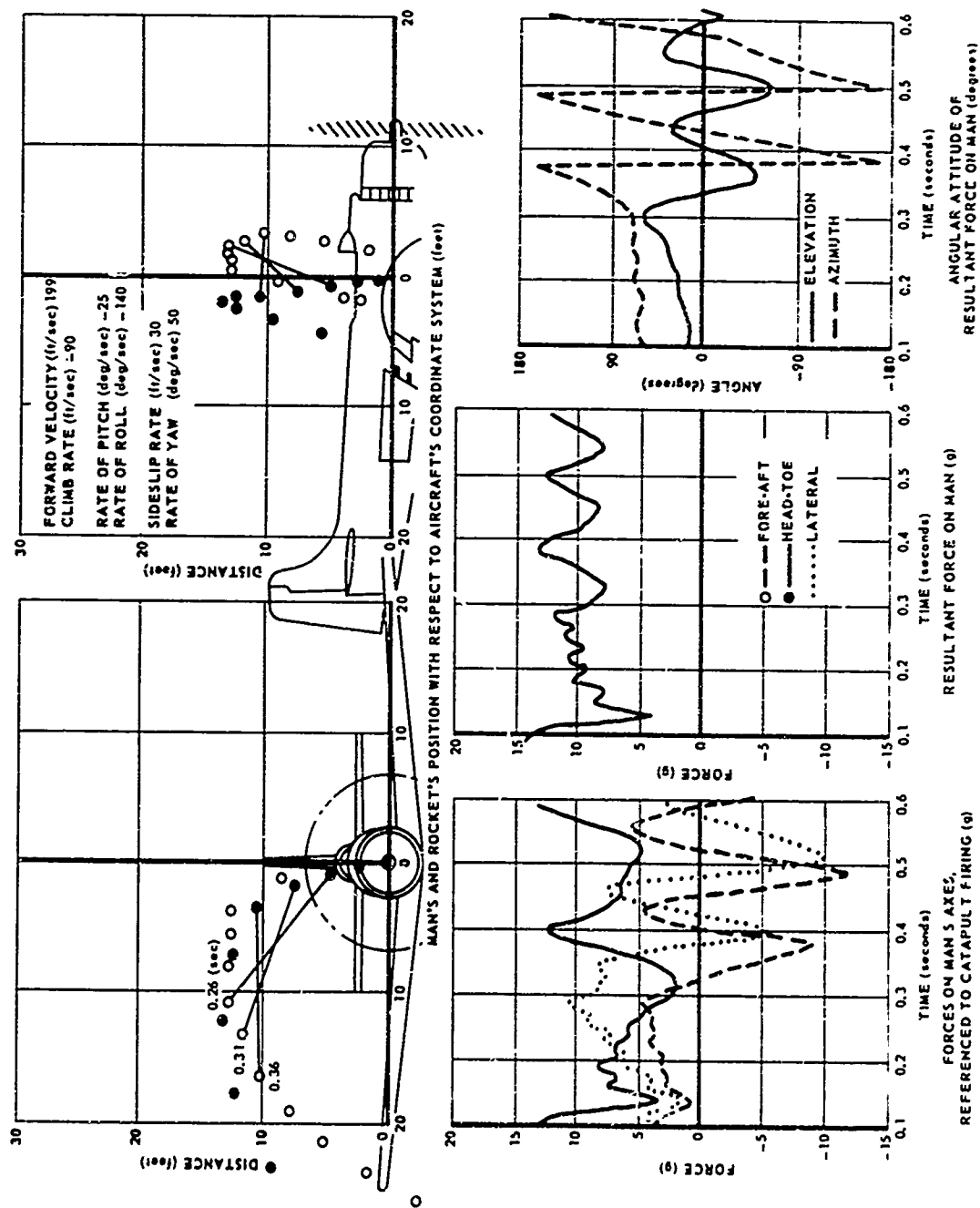


Fig. 12 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 3

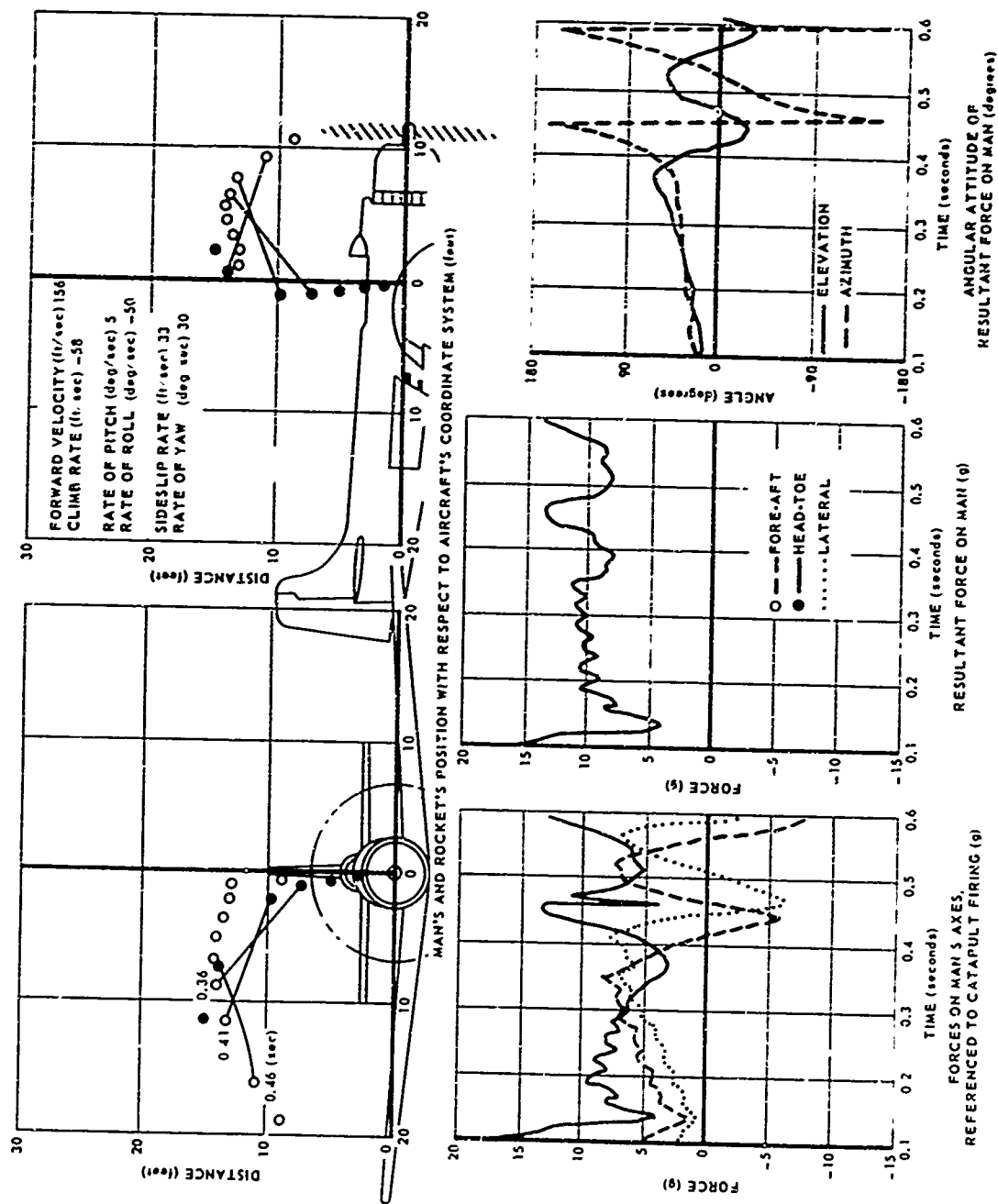


Fig. 13 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 4

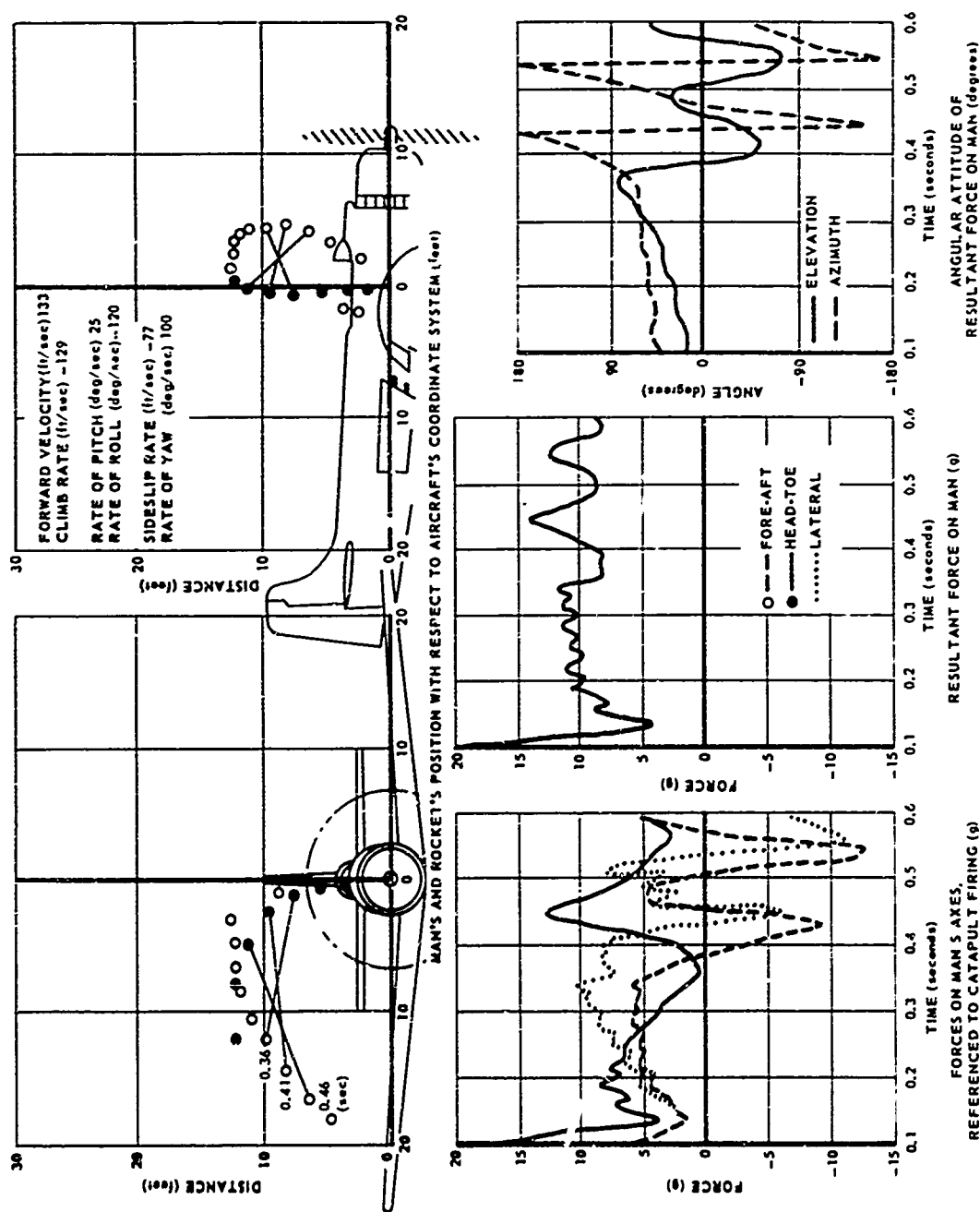


Fig. 14 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 5

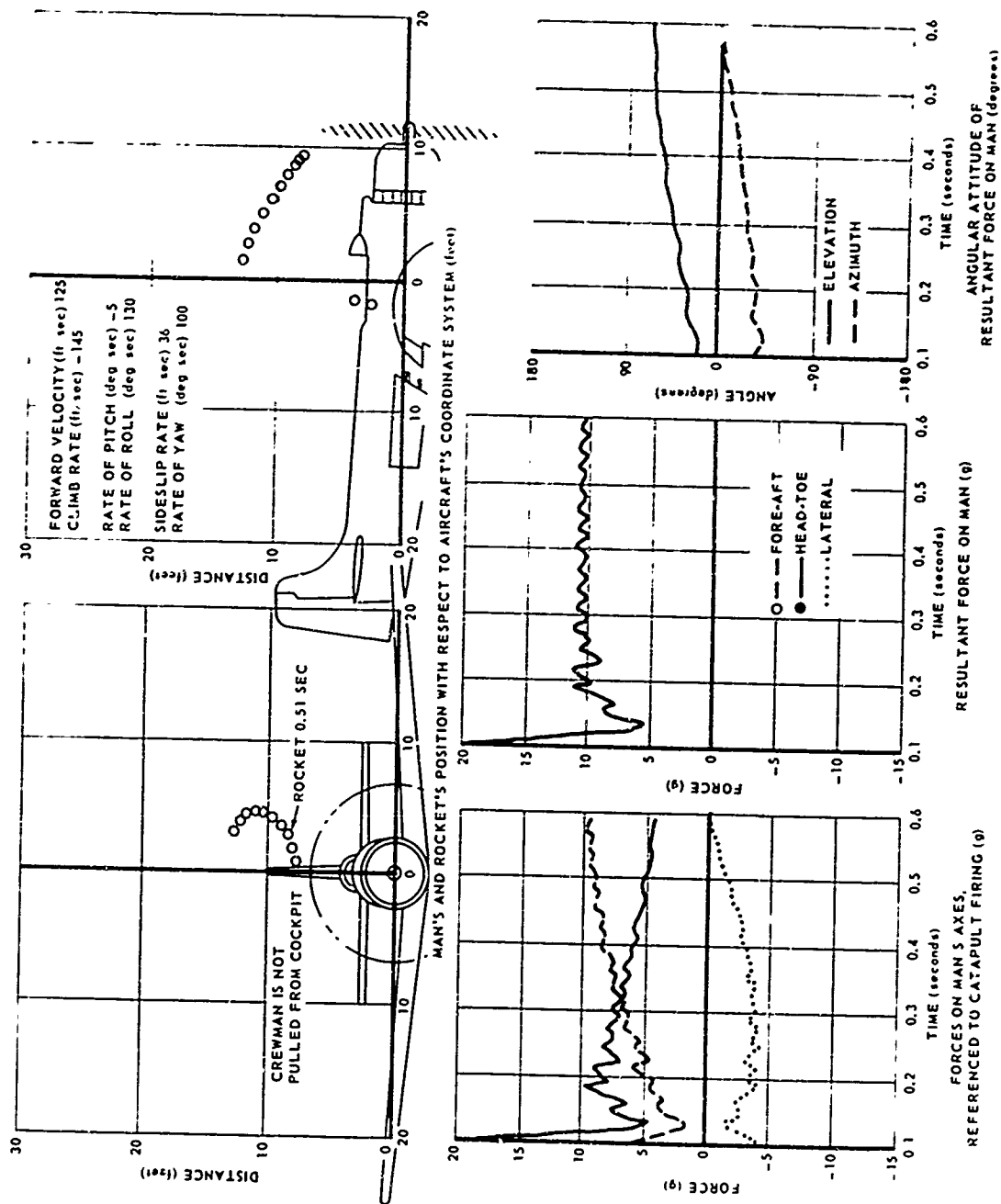


Fig. 15 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 8

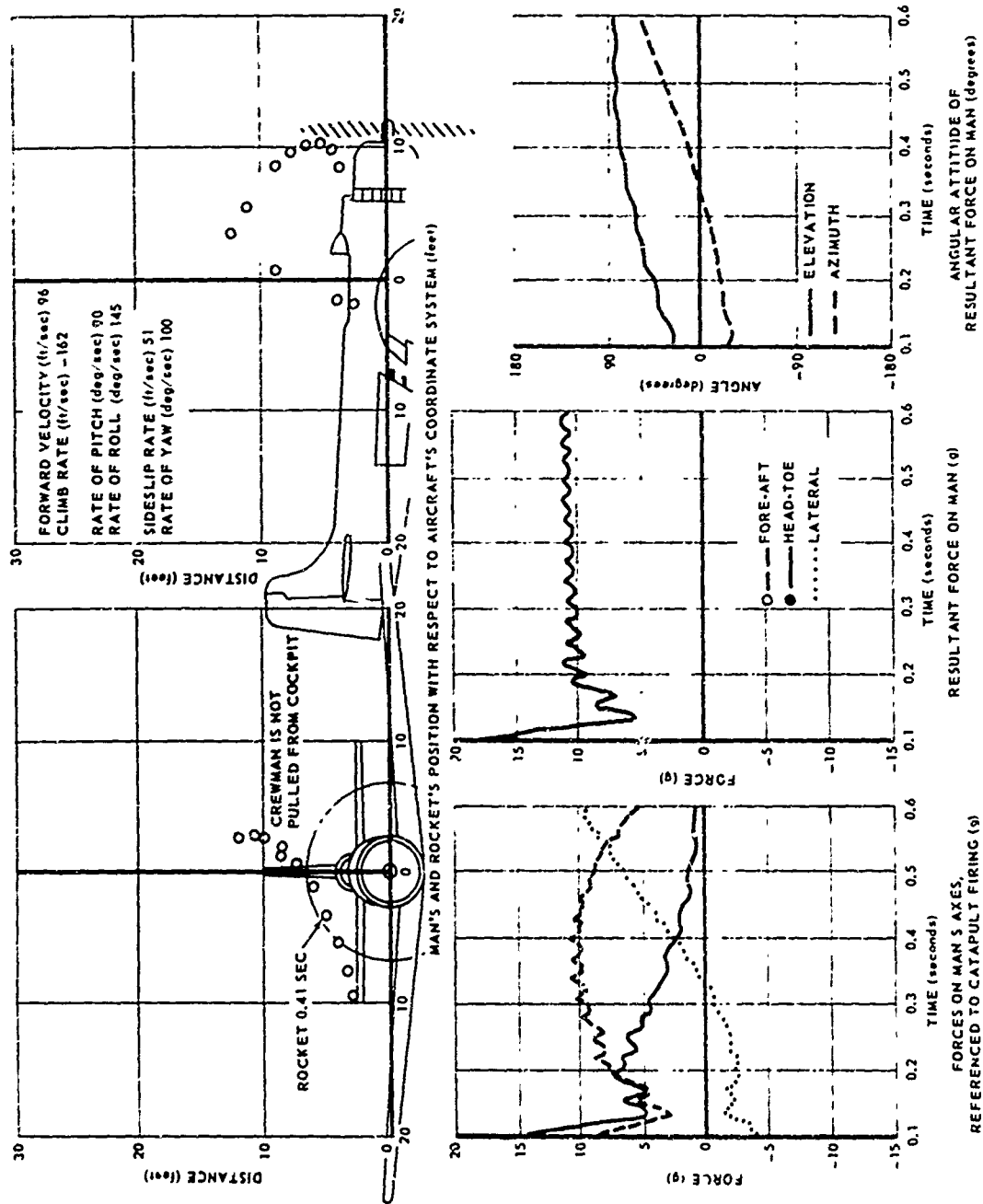


Fig. 16 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 9

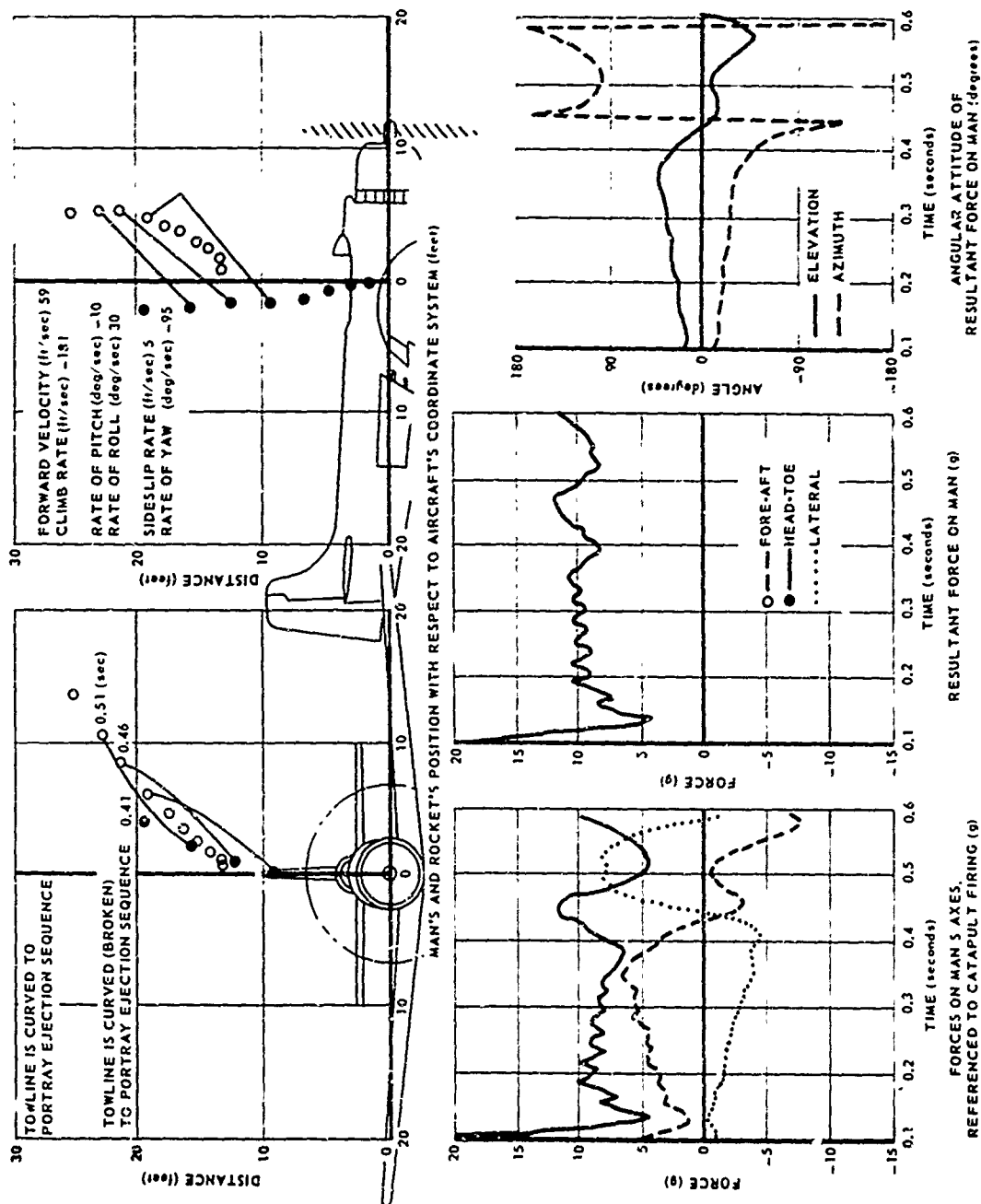


Fig. 17 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 10

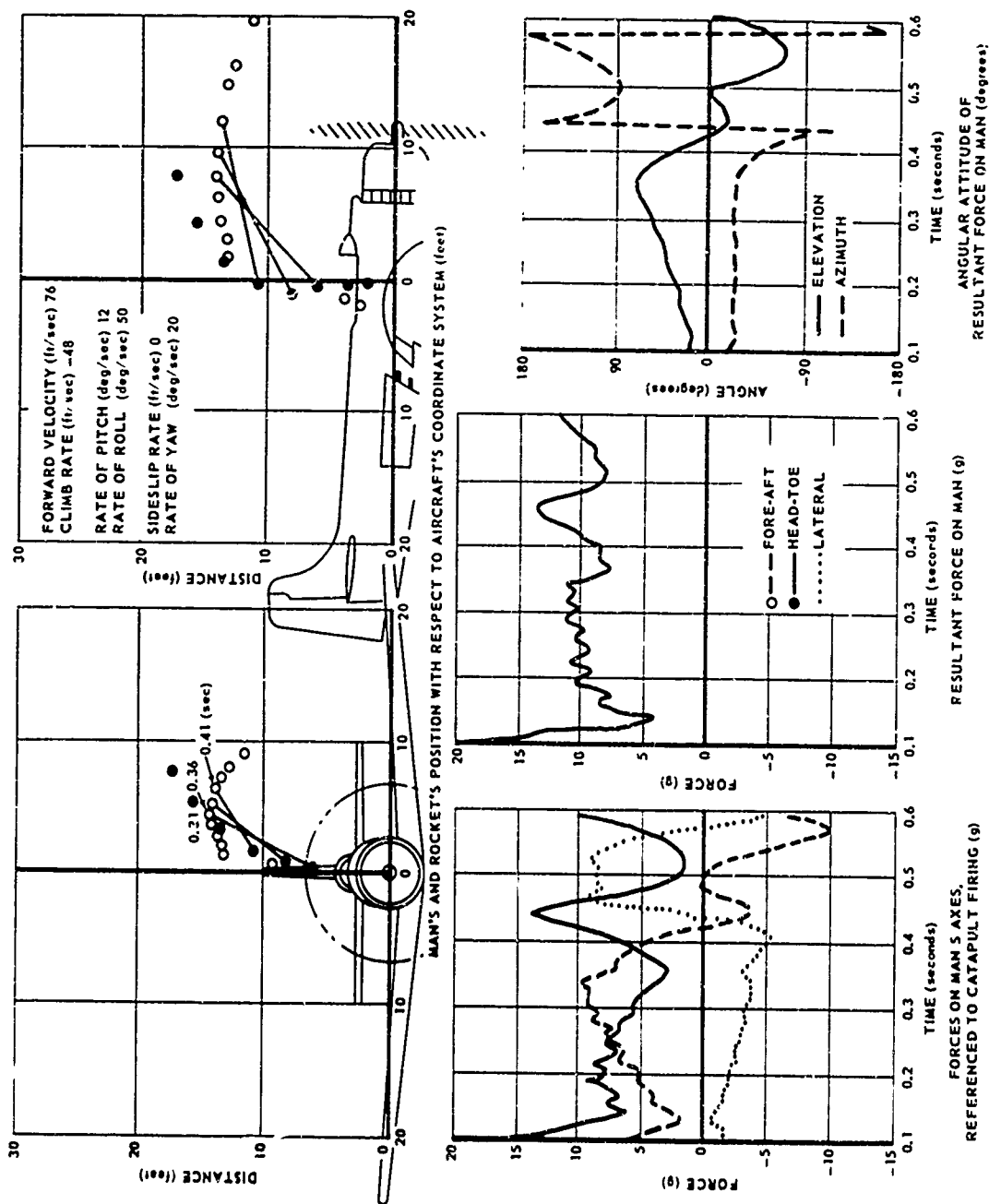


Fig. 18 Simulation Results, Three-Dimensional Tractor Rocket
Ejection Studies, Condition 11

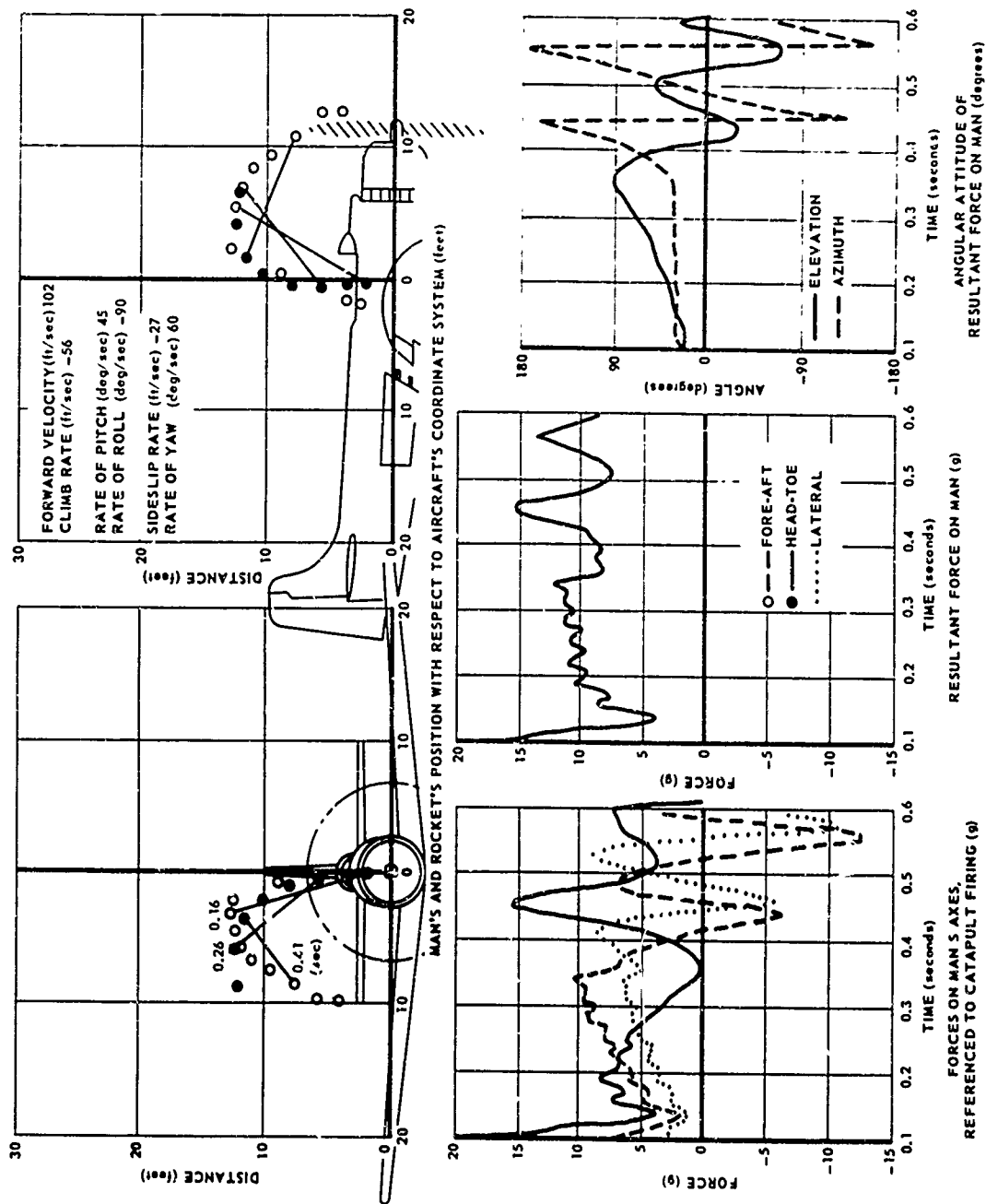


Fig. 19 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 12

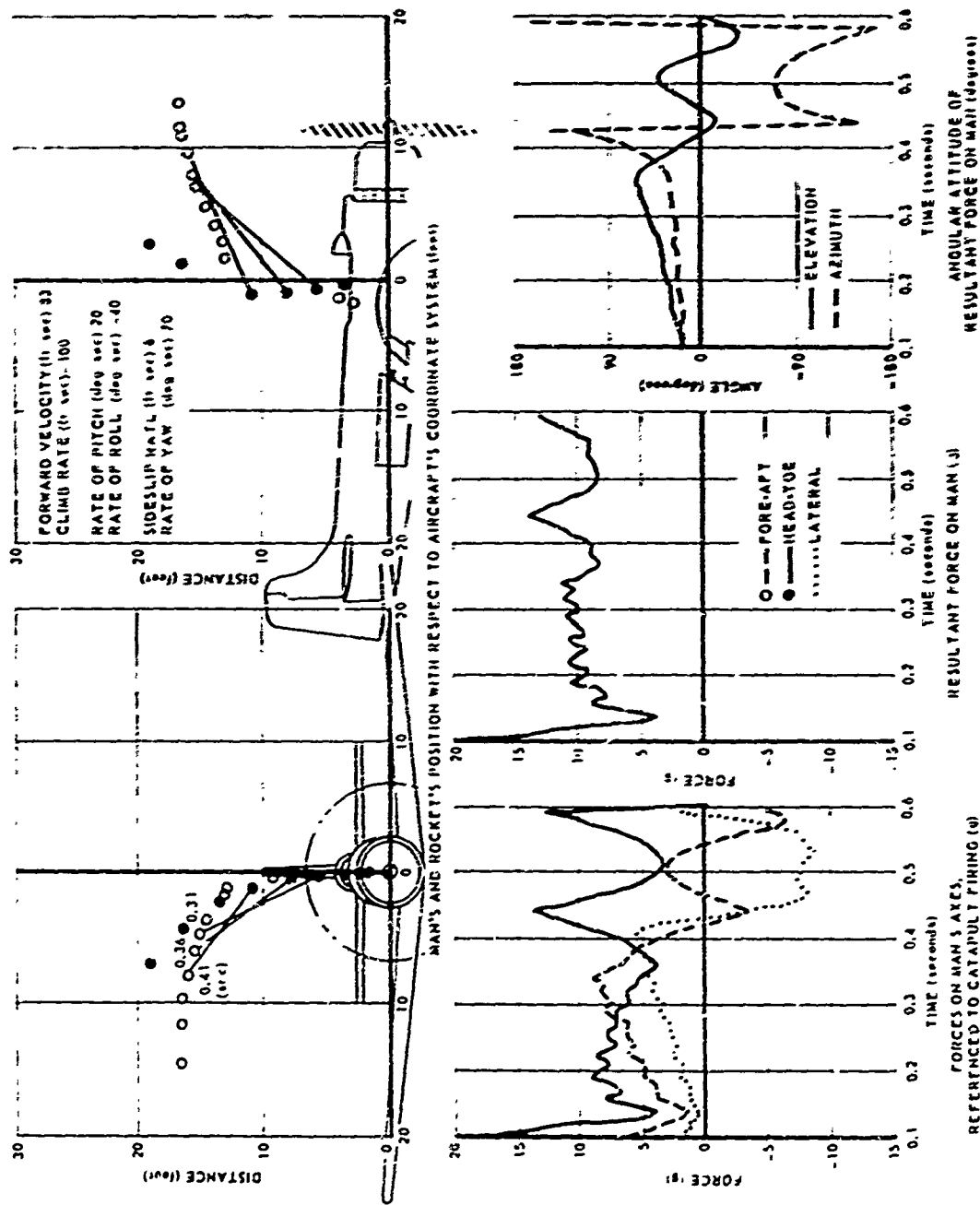


Fig. 20 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 13

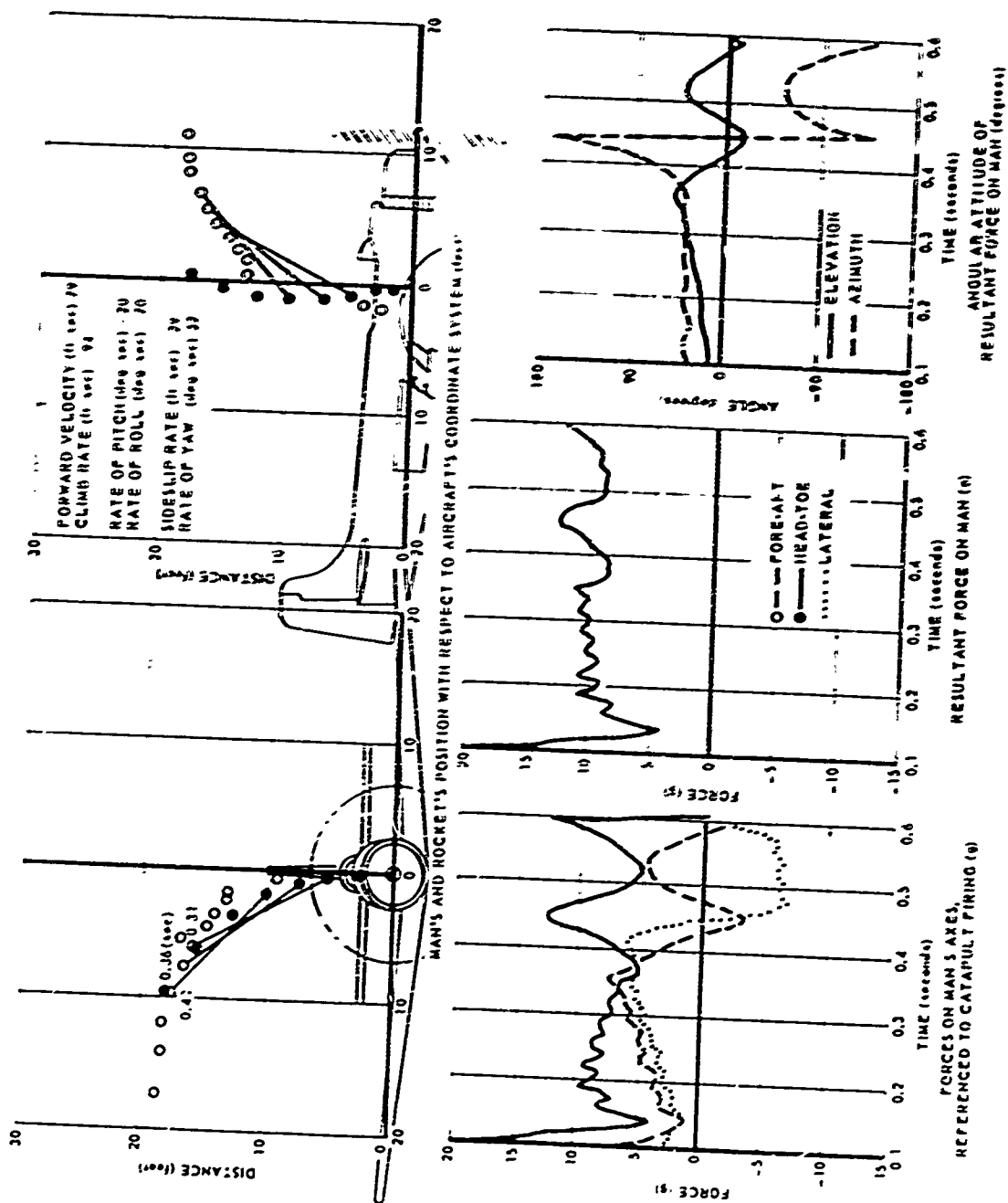
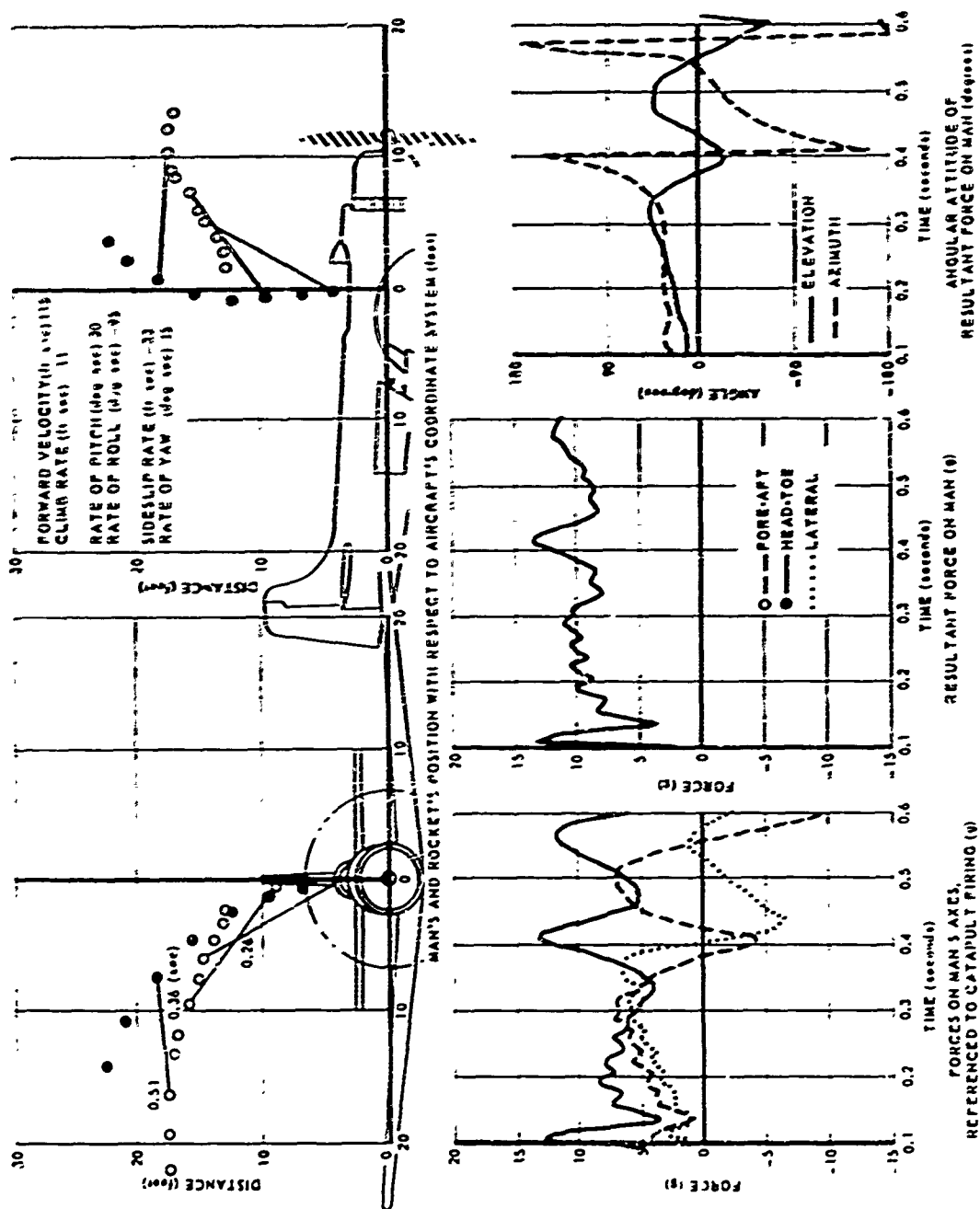


Fig. 21 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition I-4



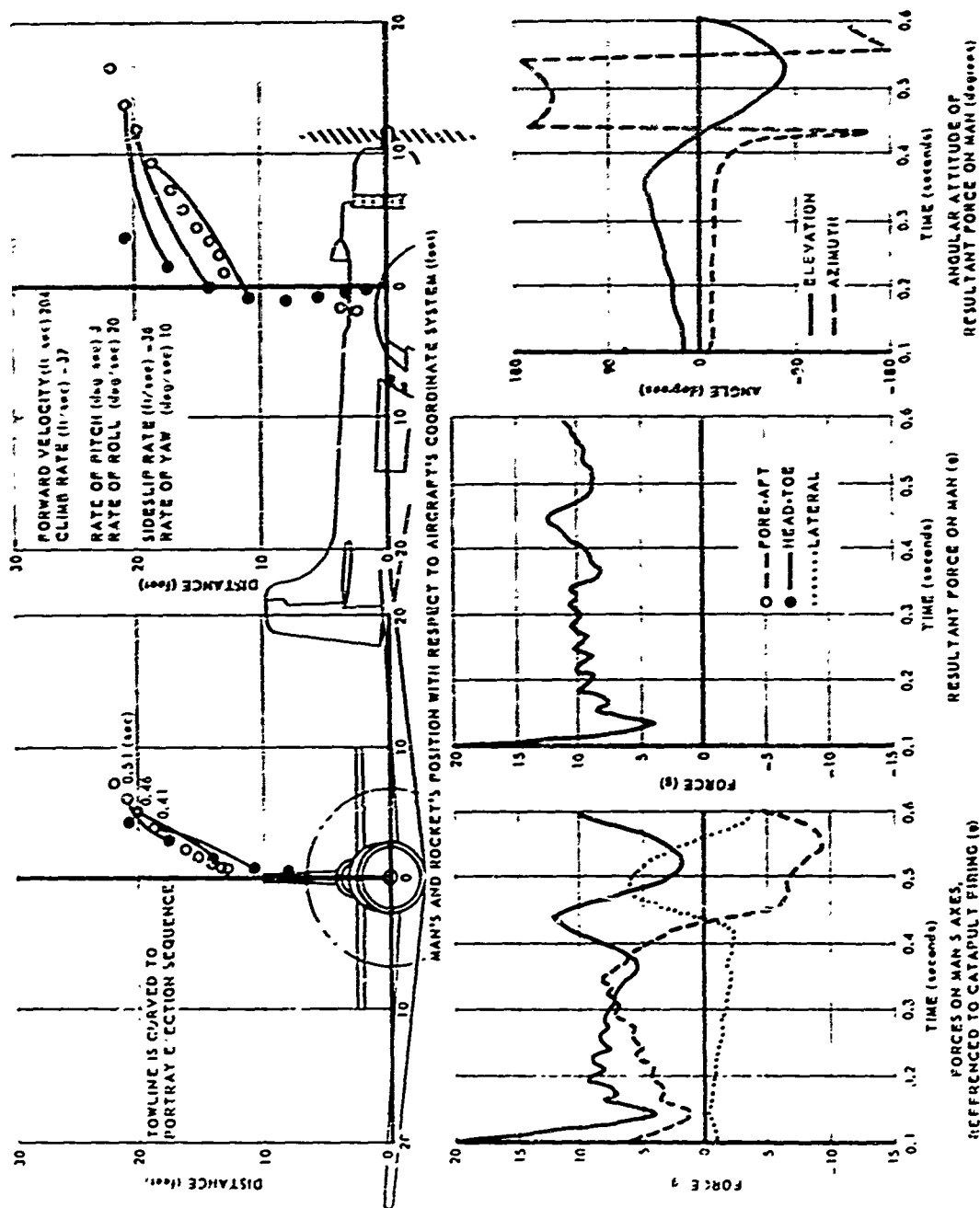


Fig. 23 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 16

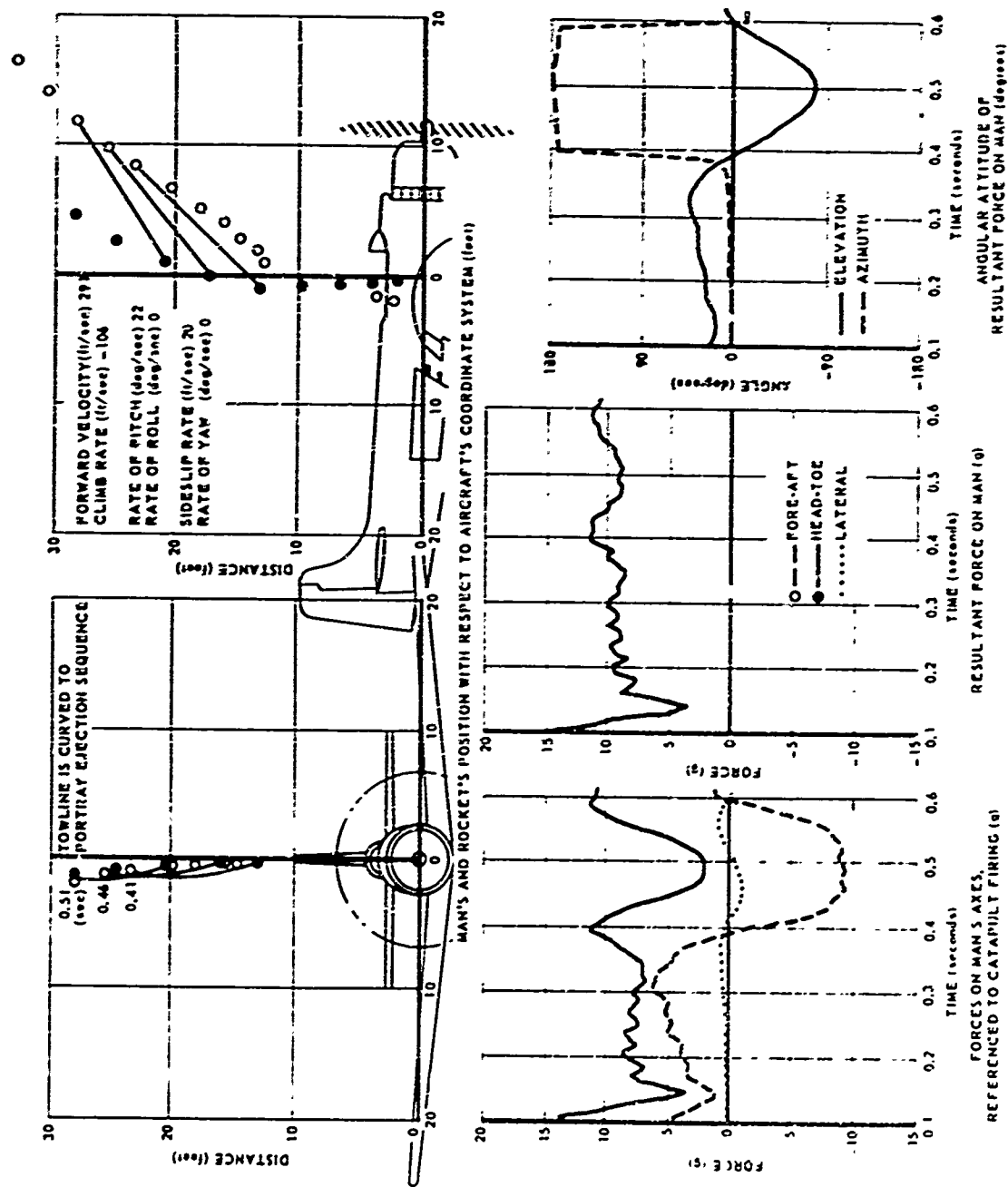


Fig. 24 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 17

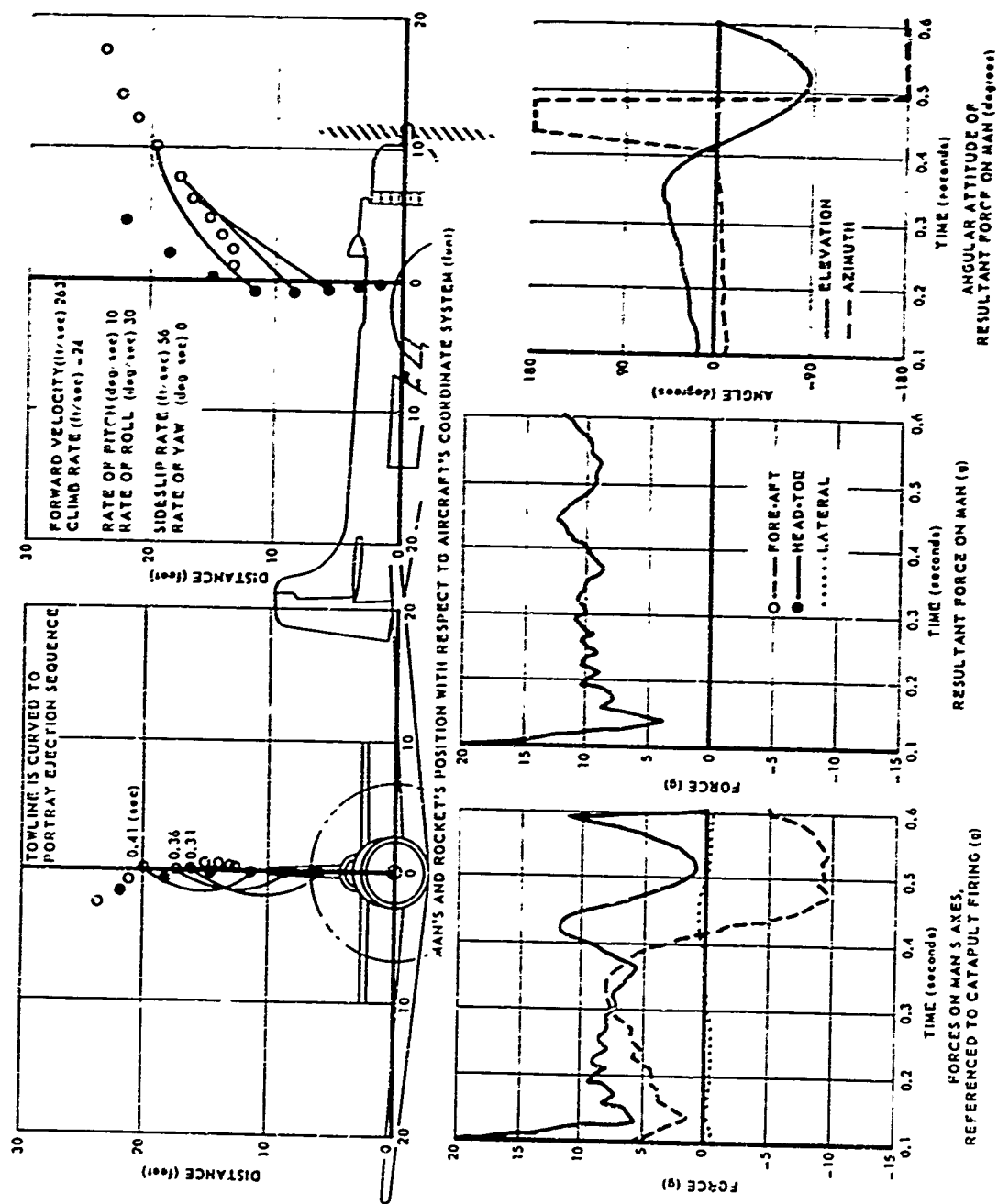


Fig. 25 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 18

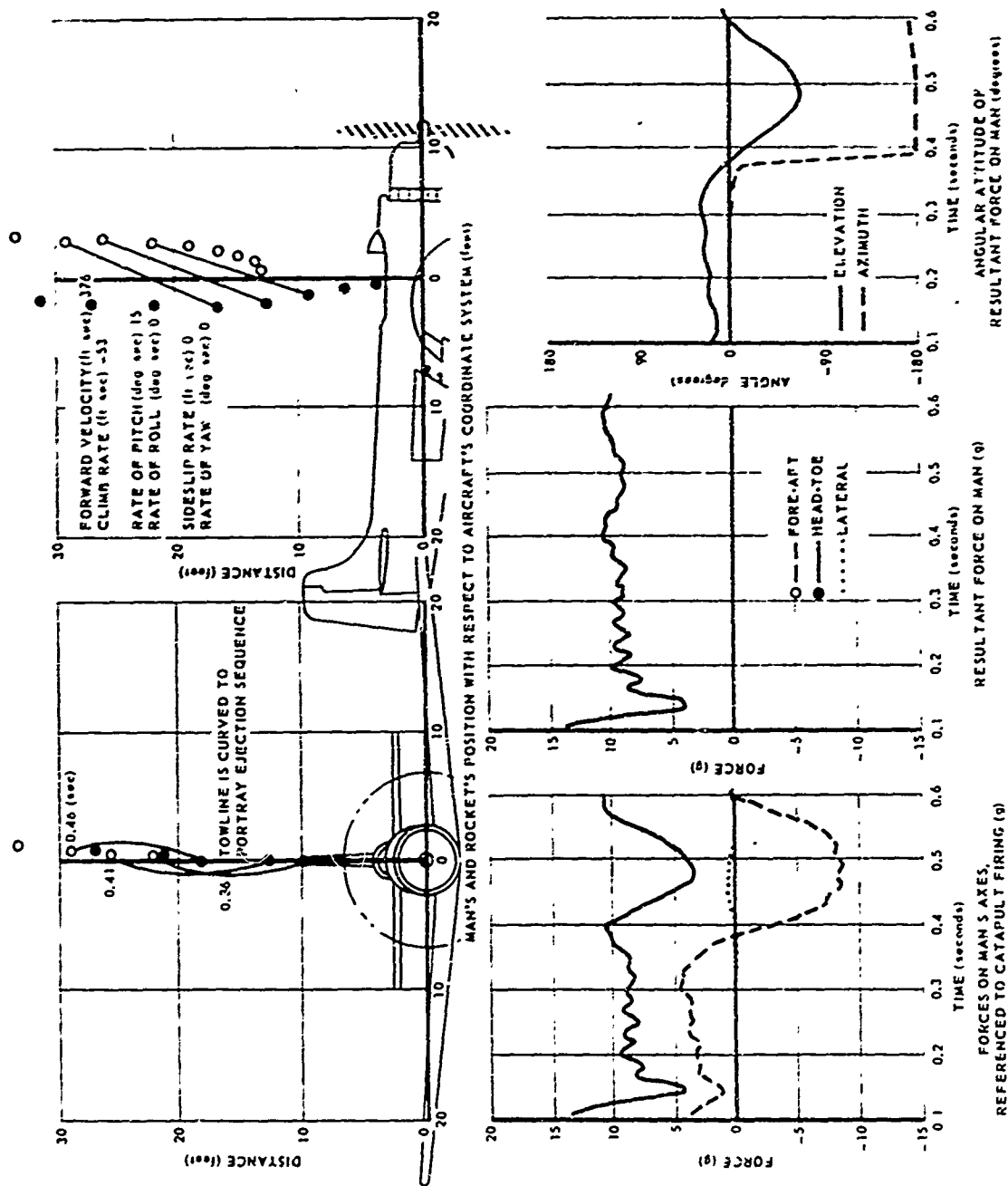


Fig. 26 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 19

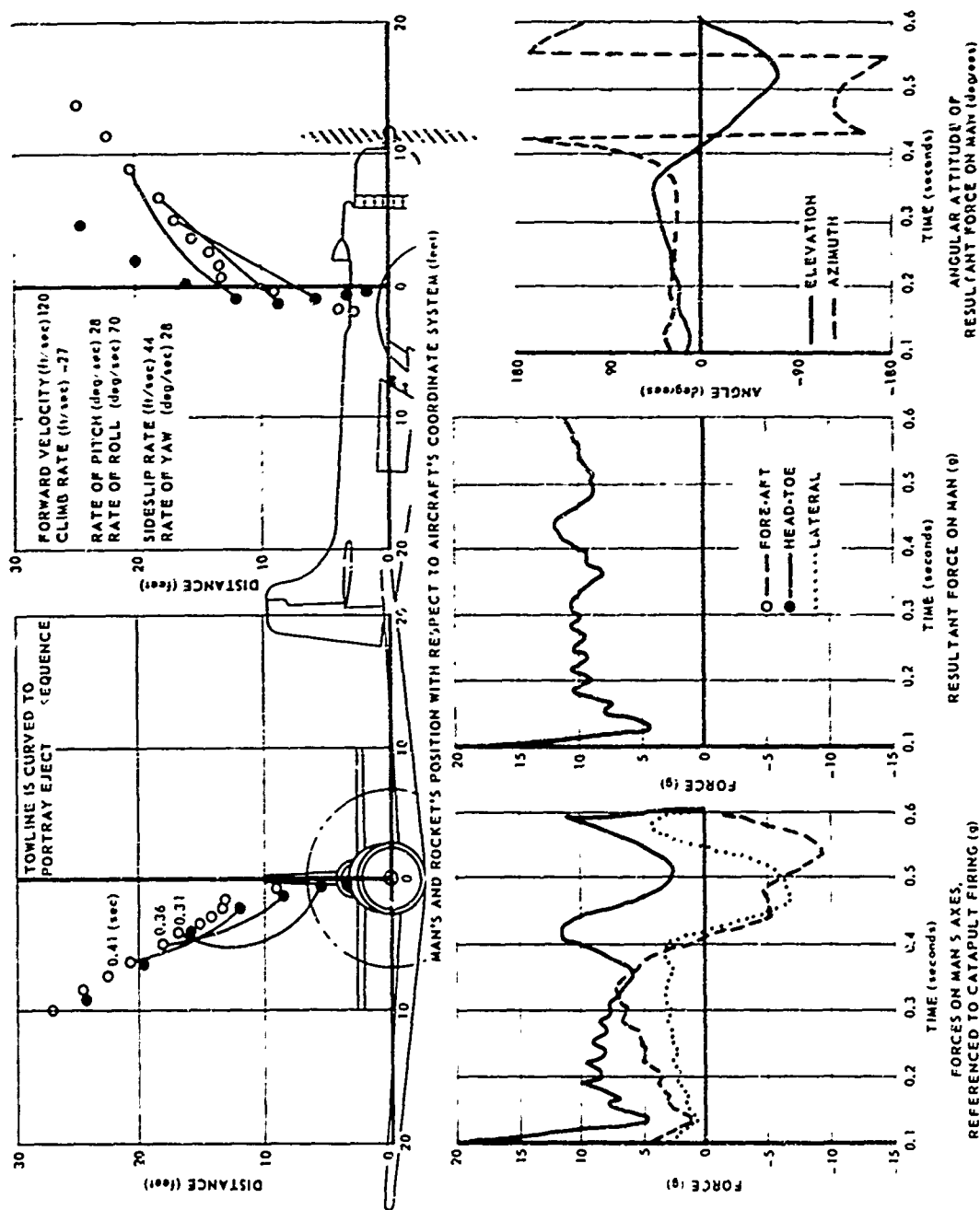


Fig. 27 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 20

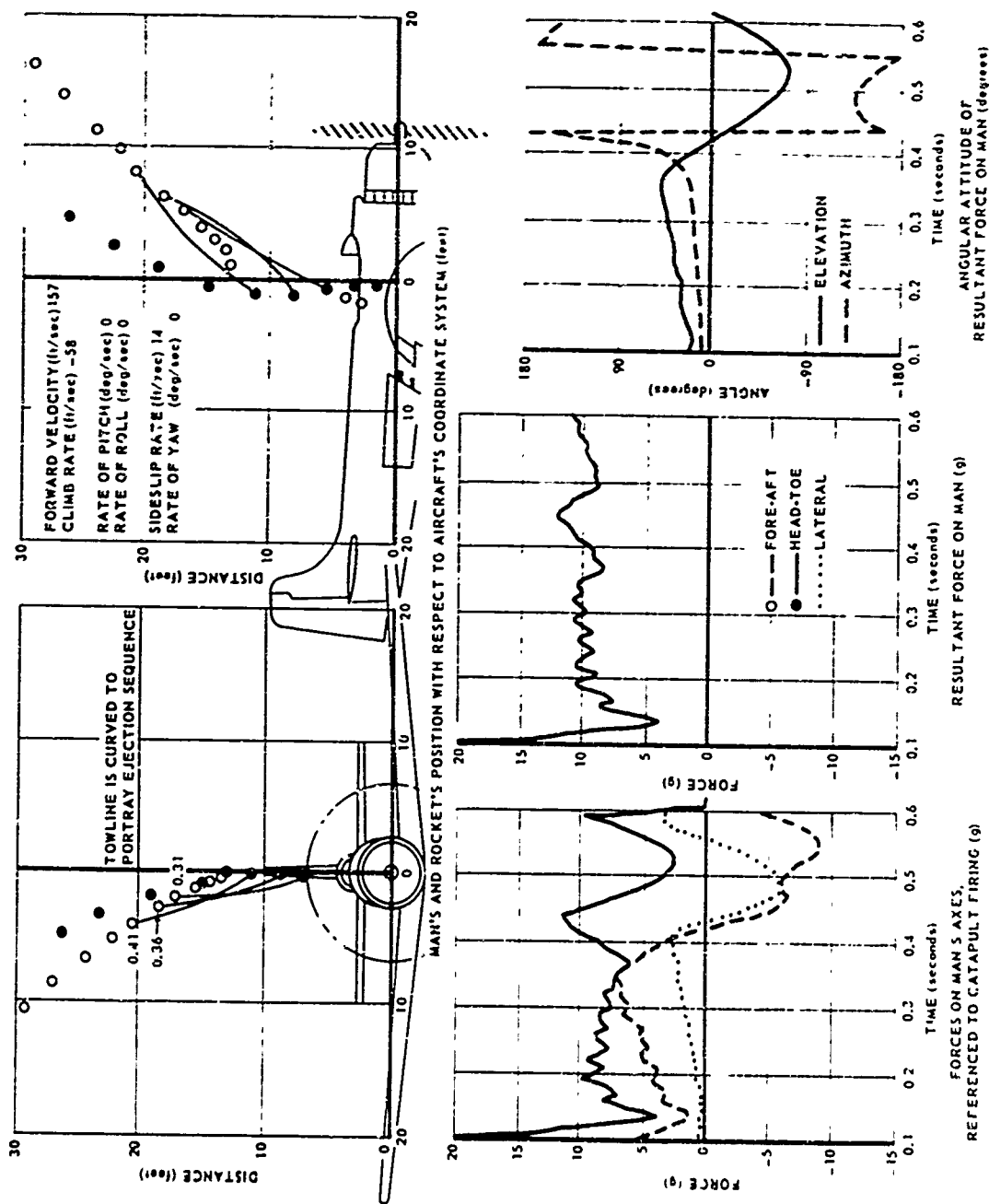


Fig. 28 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 21

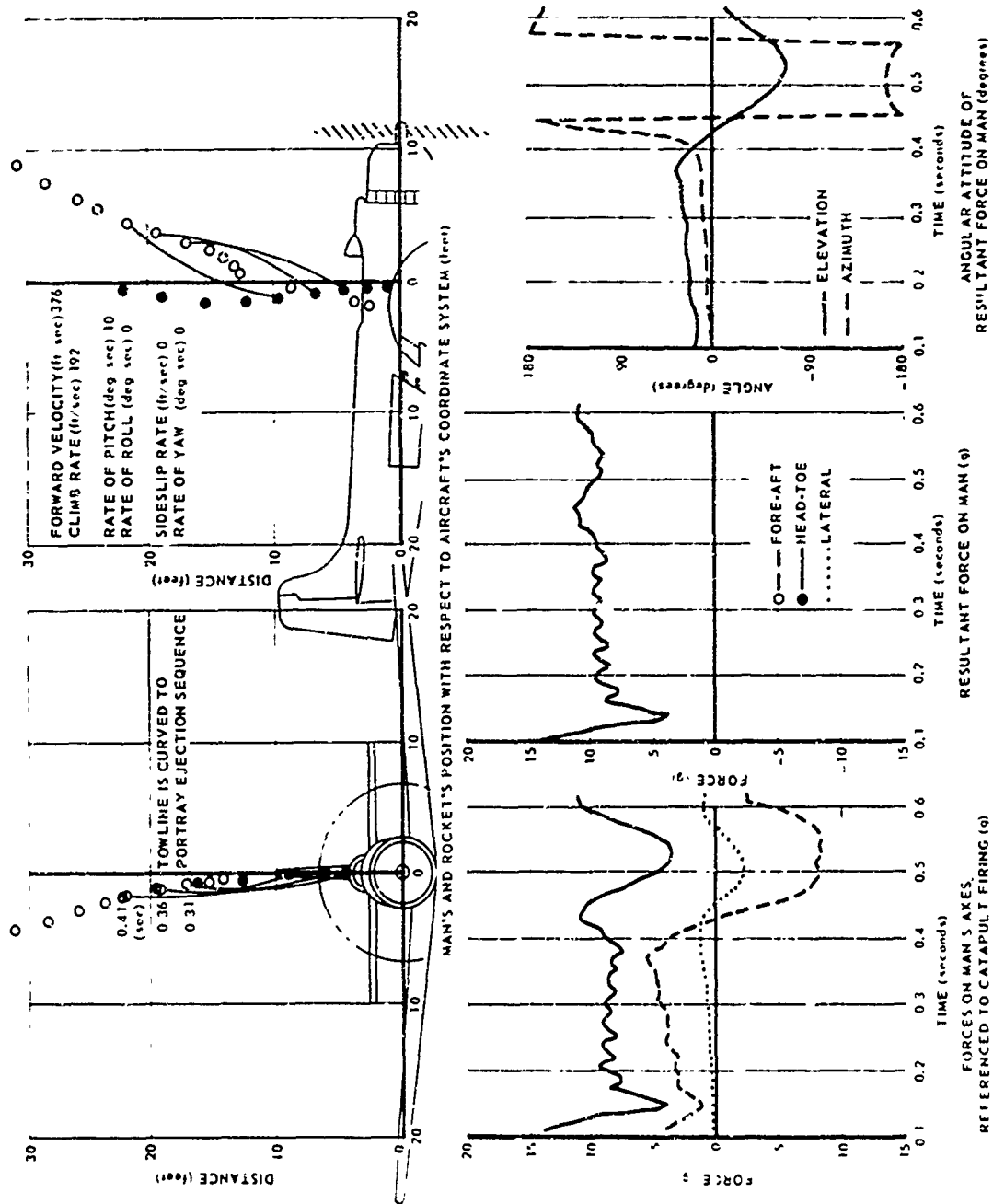


Fig. 29 Simulation Results, Three-Dimensional Tractor Rocket
Ejection Studies, Condition 22

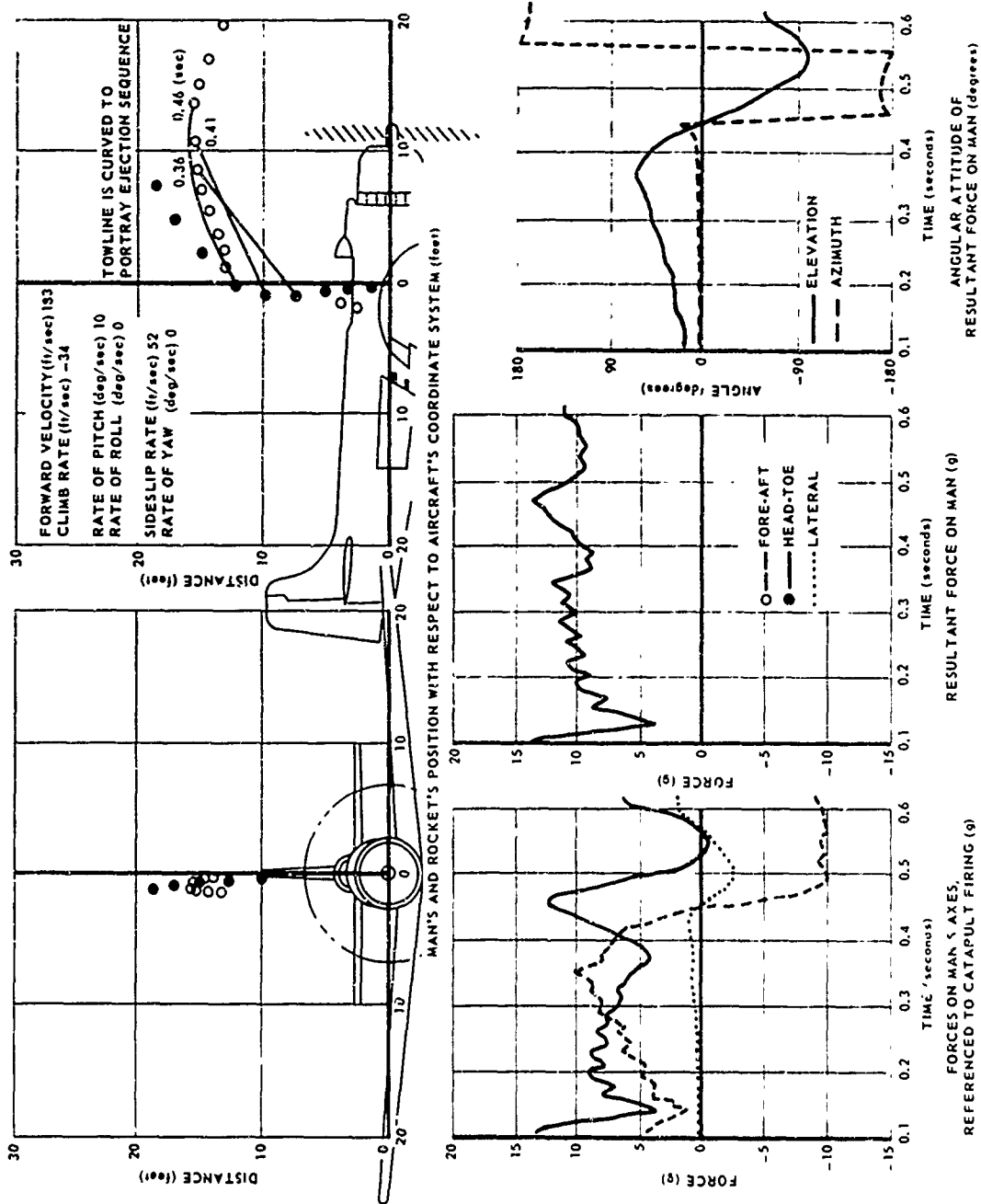


Fig. 30 Simulation Results, Three-Dimensional Tractor Rocket
Ejection Studies, Condition 23

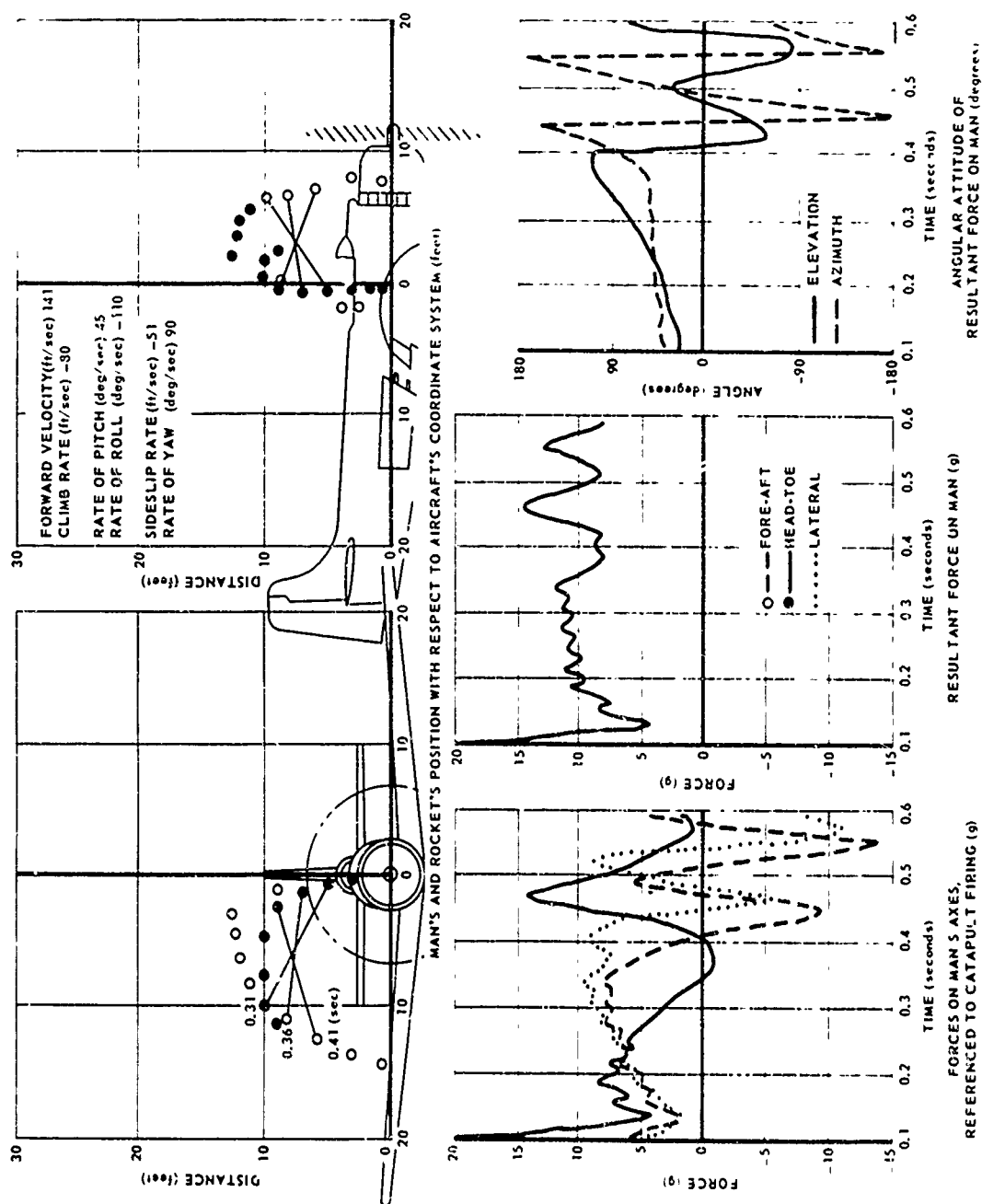


Fig. 31 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 24

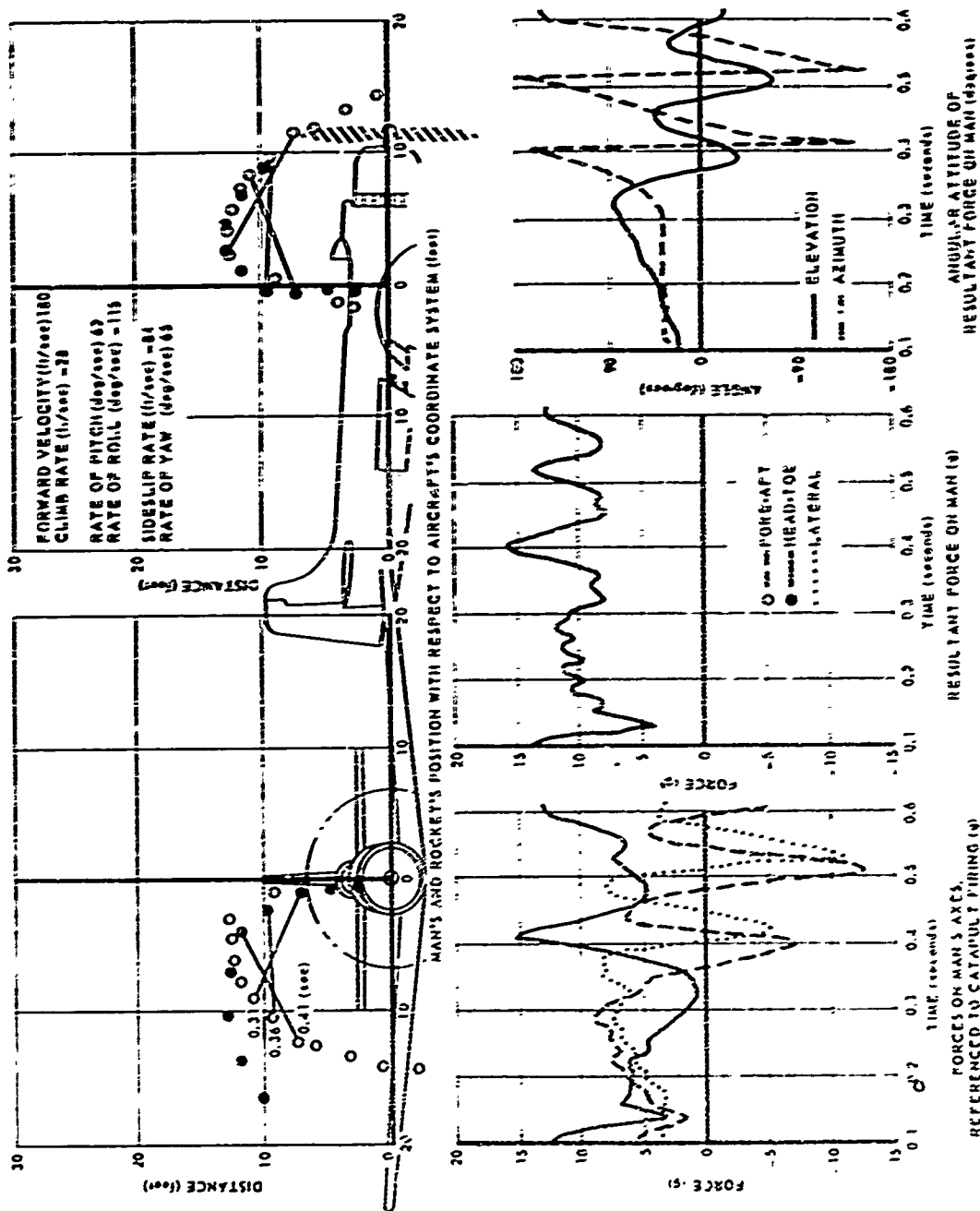


Fig. 32 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 25

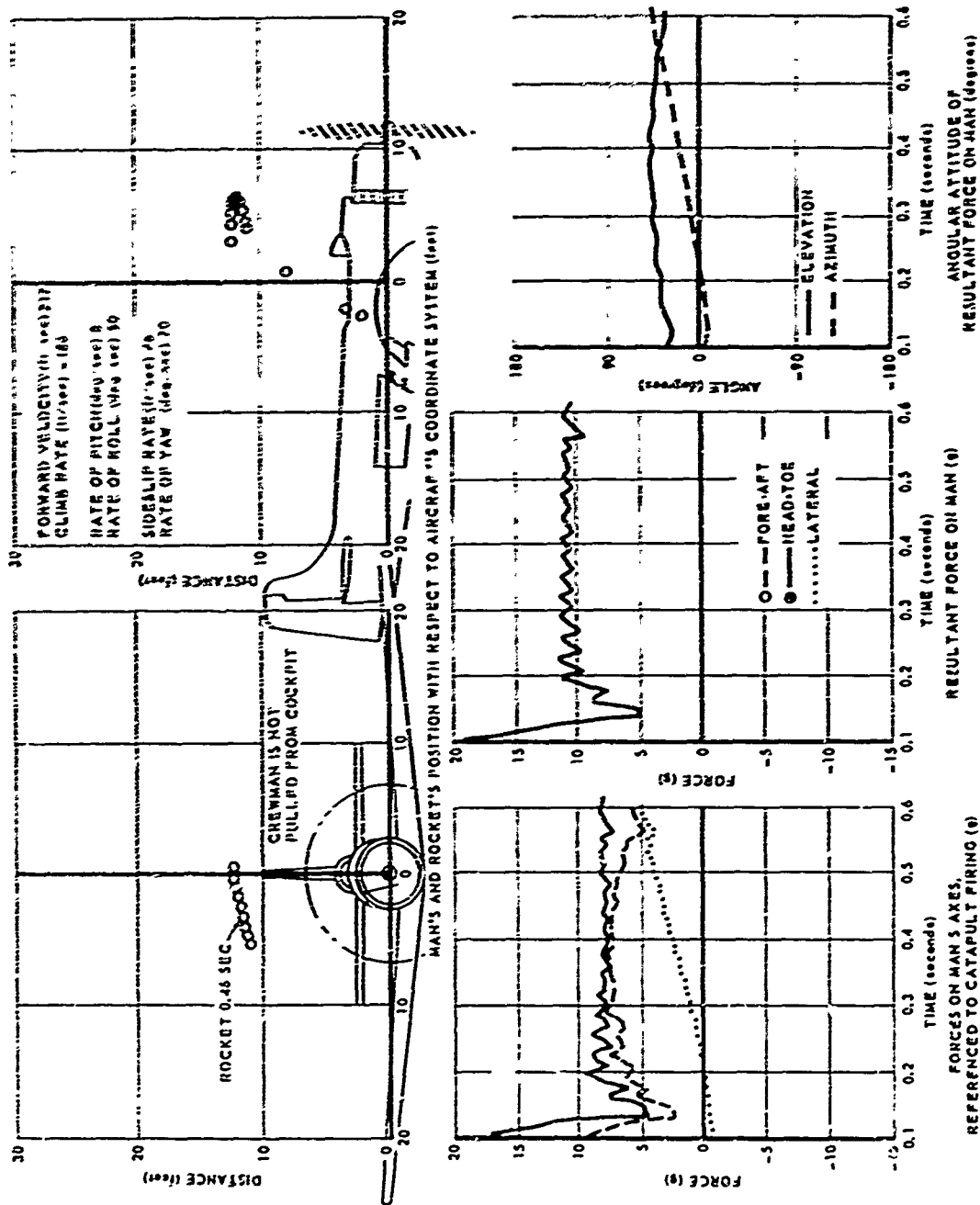


Fig. 33 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 1b (Rocket Catapulted 27° ahead of Vertical)

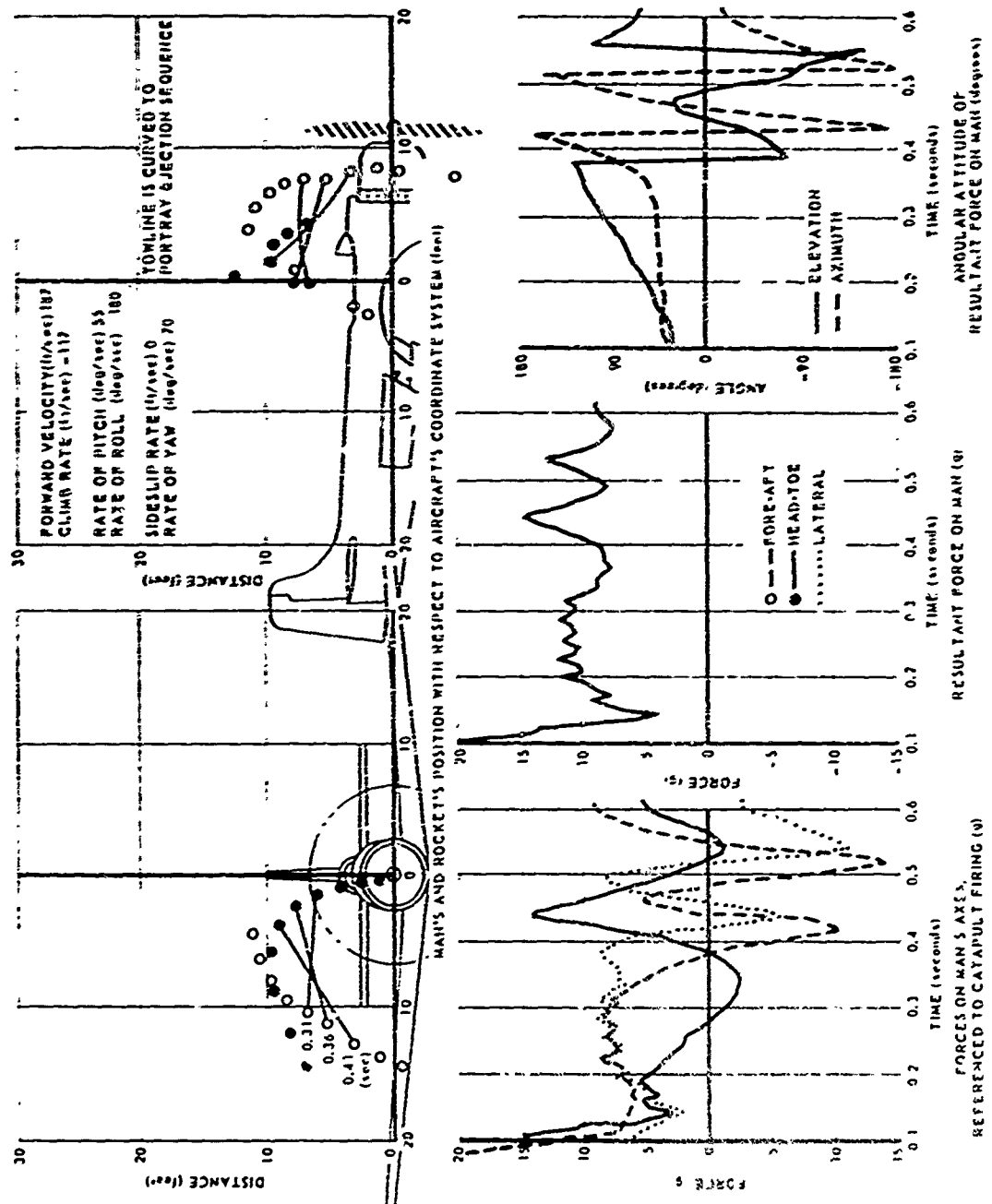


Fig. 34 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 2b (Rocket Catapulted 27° ahead of Vertical)

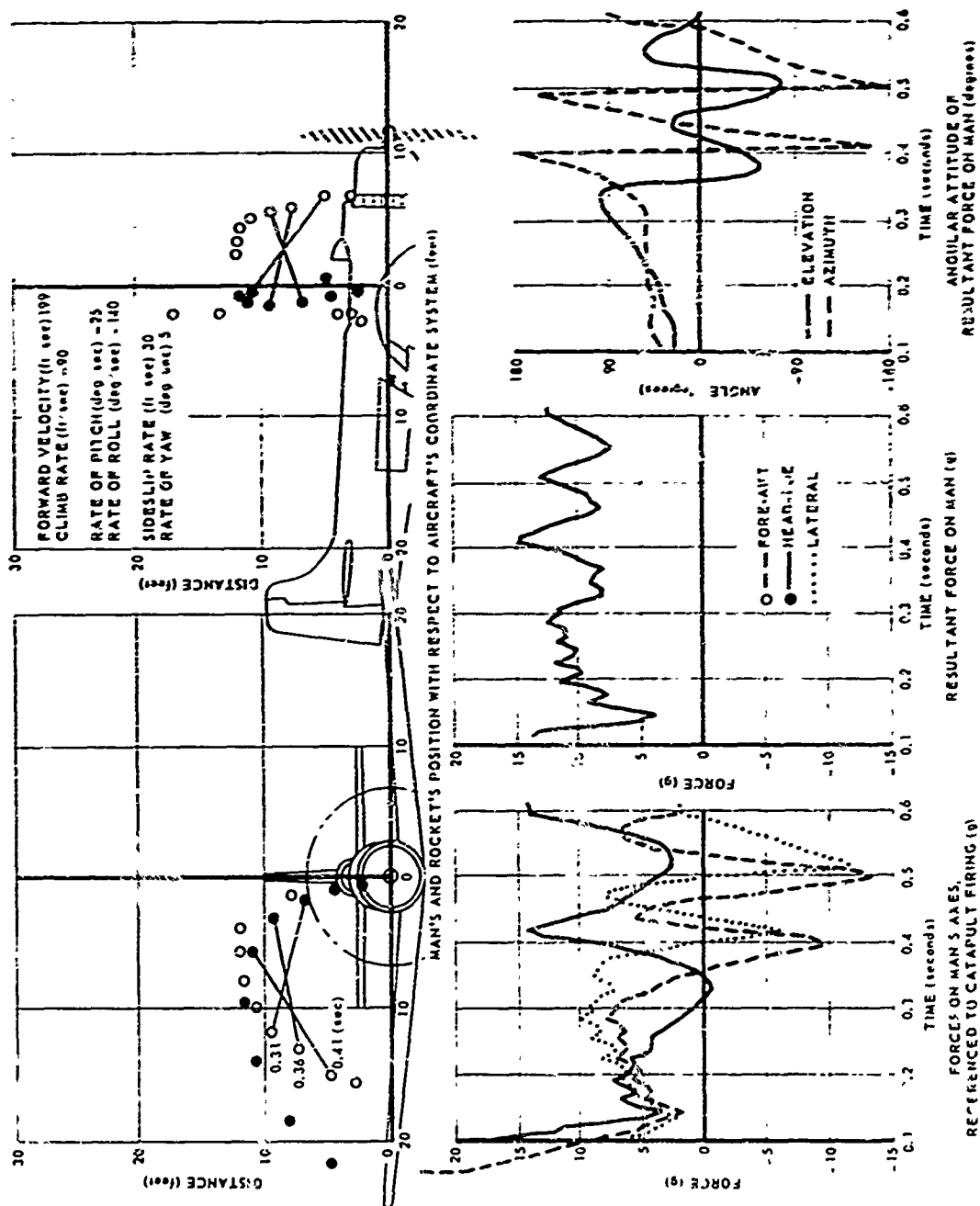


Fig. 35 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 3b (Rocket Catapulted 27° ahead of Vertical)

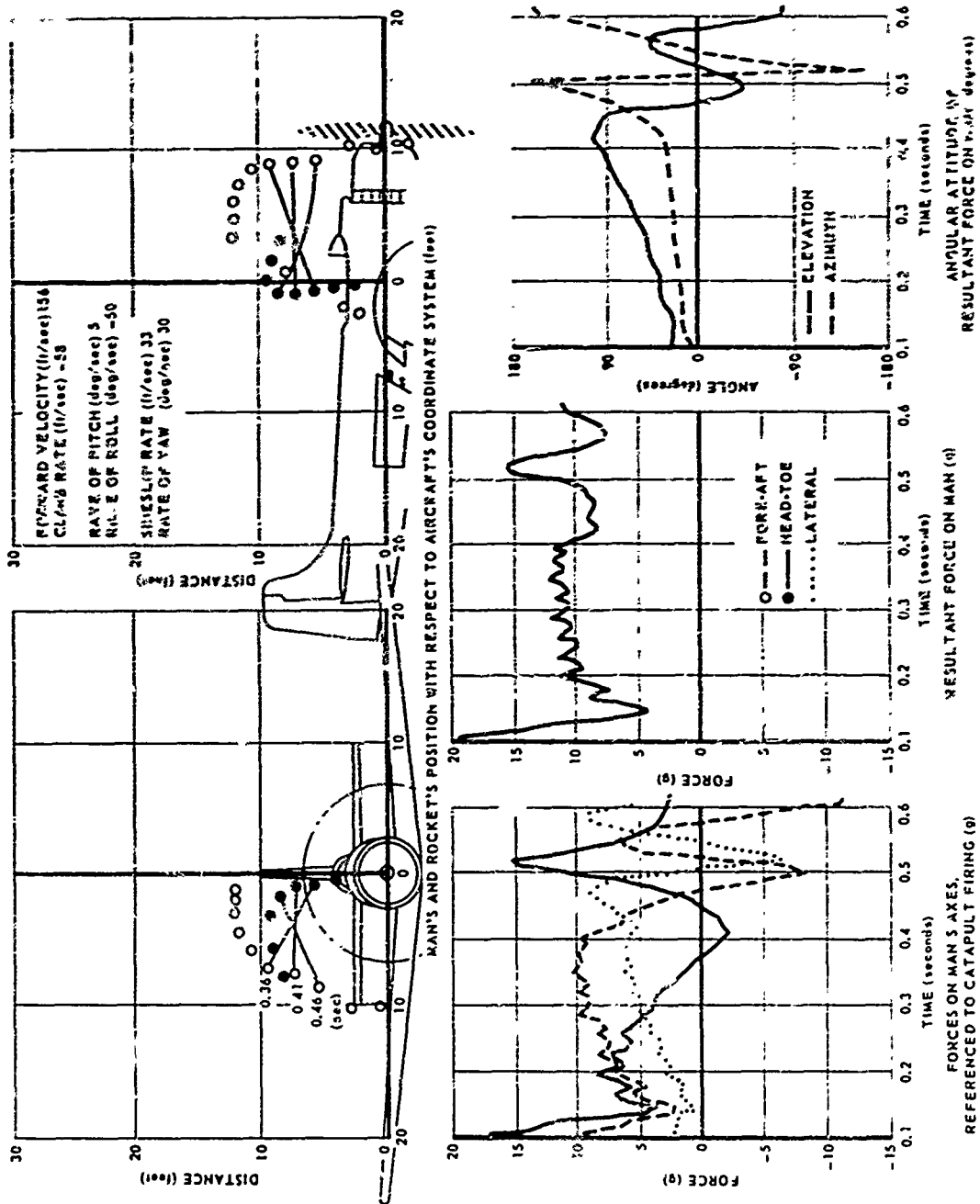


Fig. 36 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 4b (Rocket Catapult at 37° ahead of Vertical)

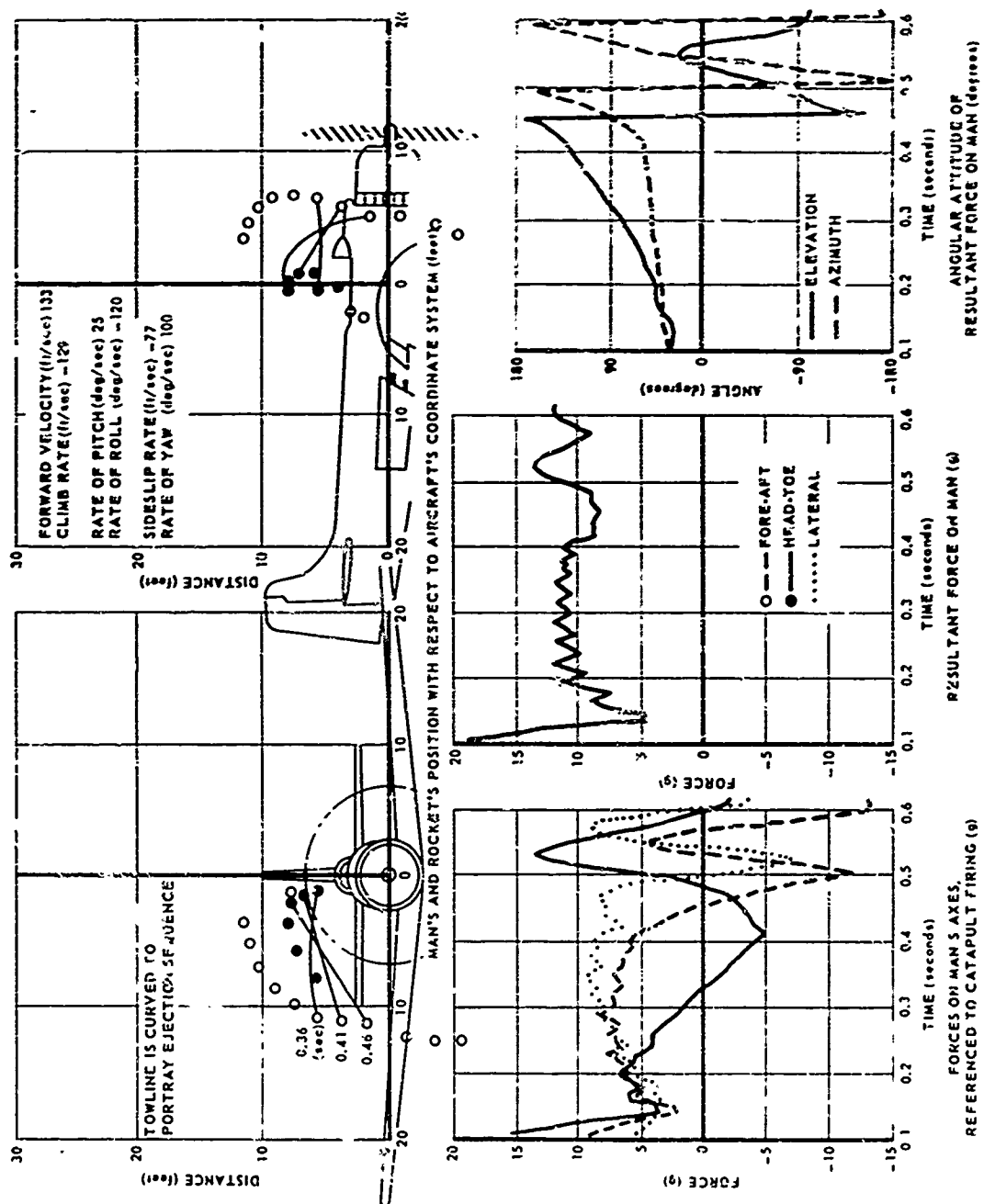


Fig. 37 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 5b (Rocket Catapulted 27° ahead of Vertical)

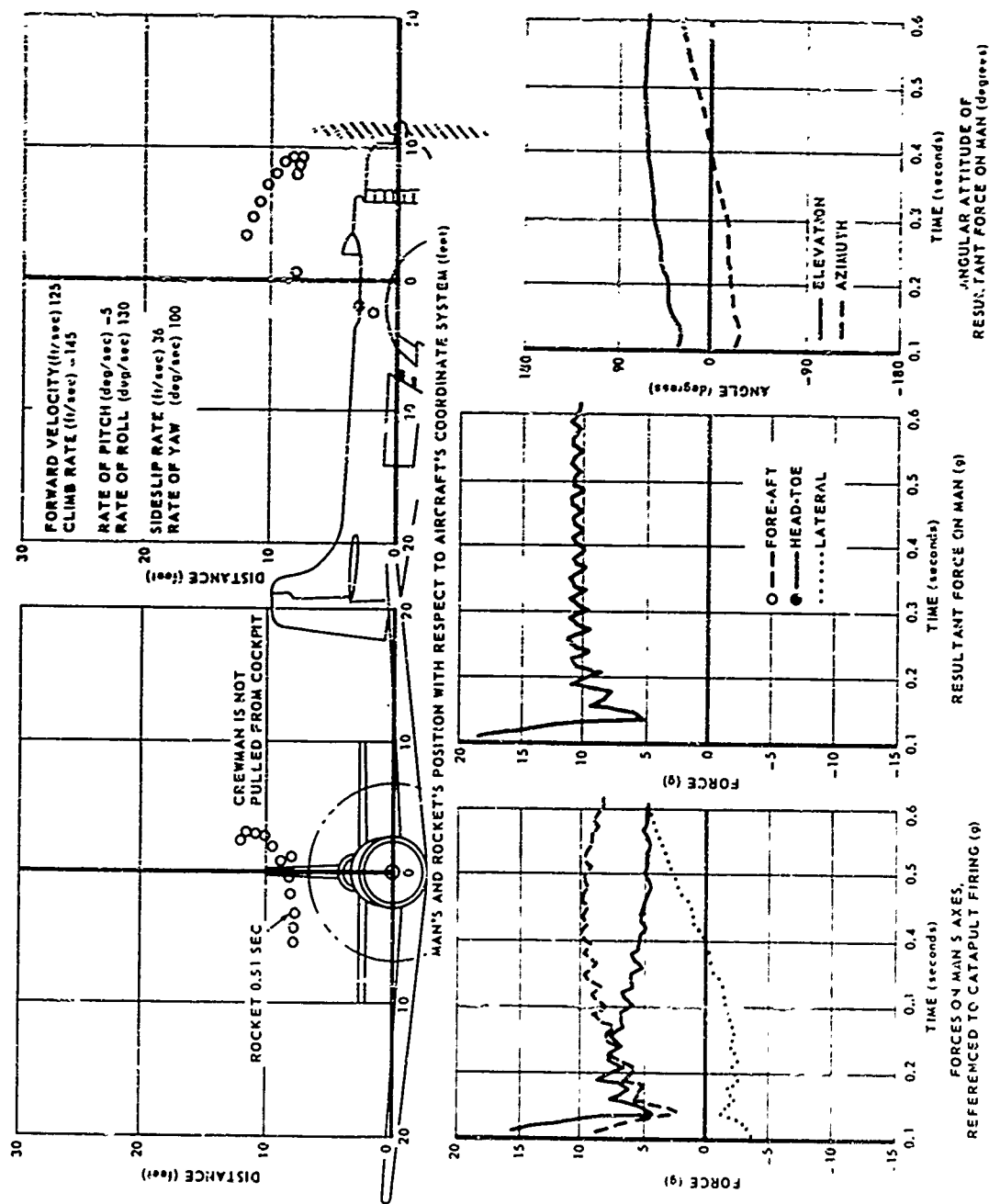


Fig. 38 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 8b (Rocket Catapulted 27° ahead of Vertical)

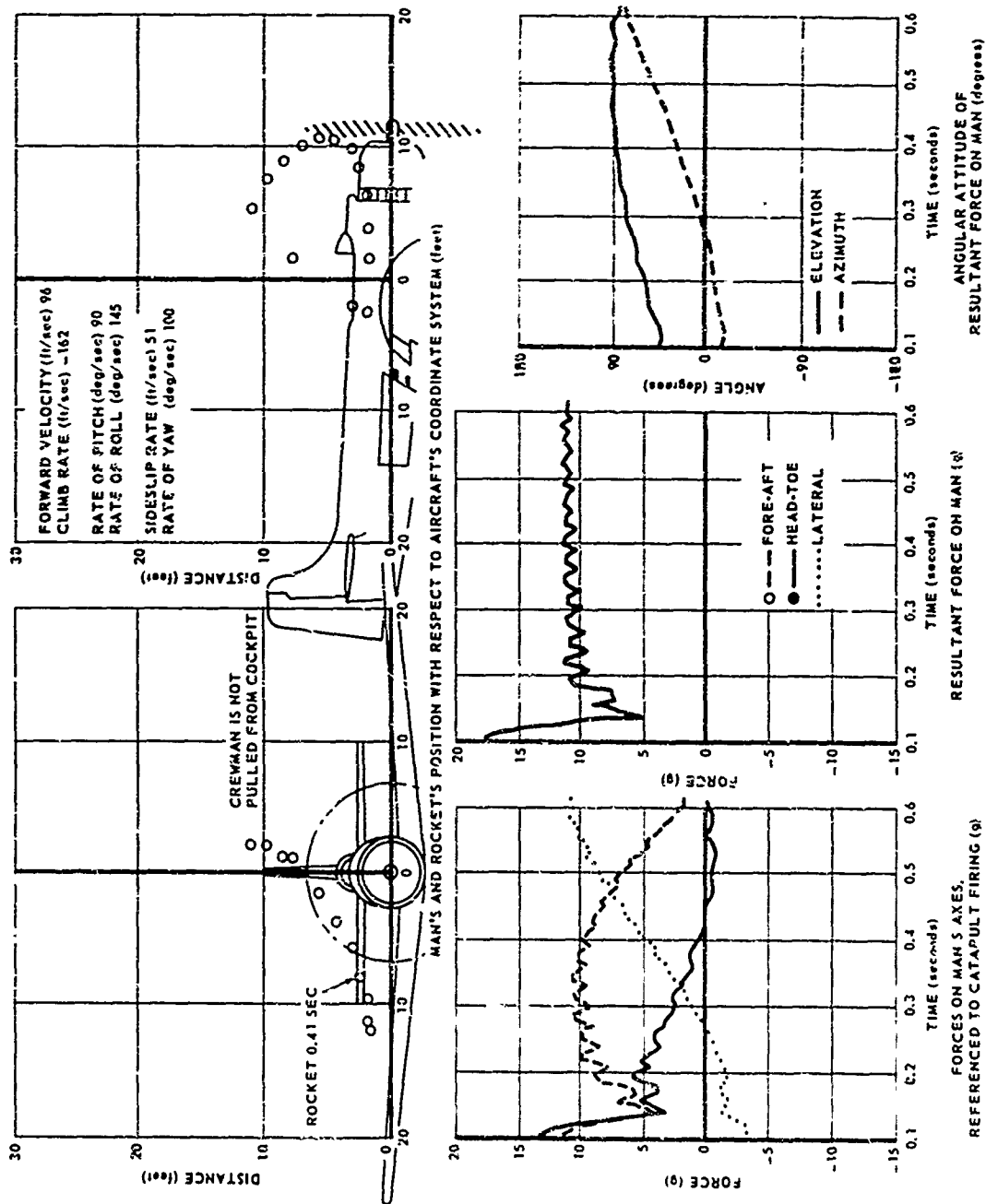


Fig. 39 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 9b (Rocket Catapulted 27° ahead of Vertical)

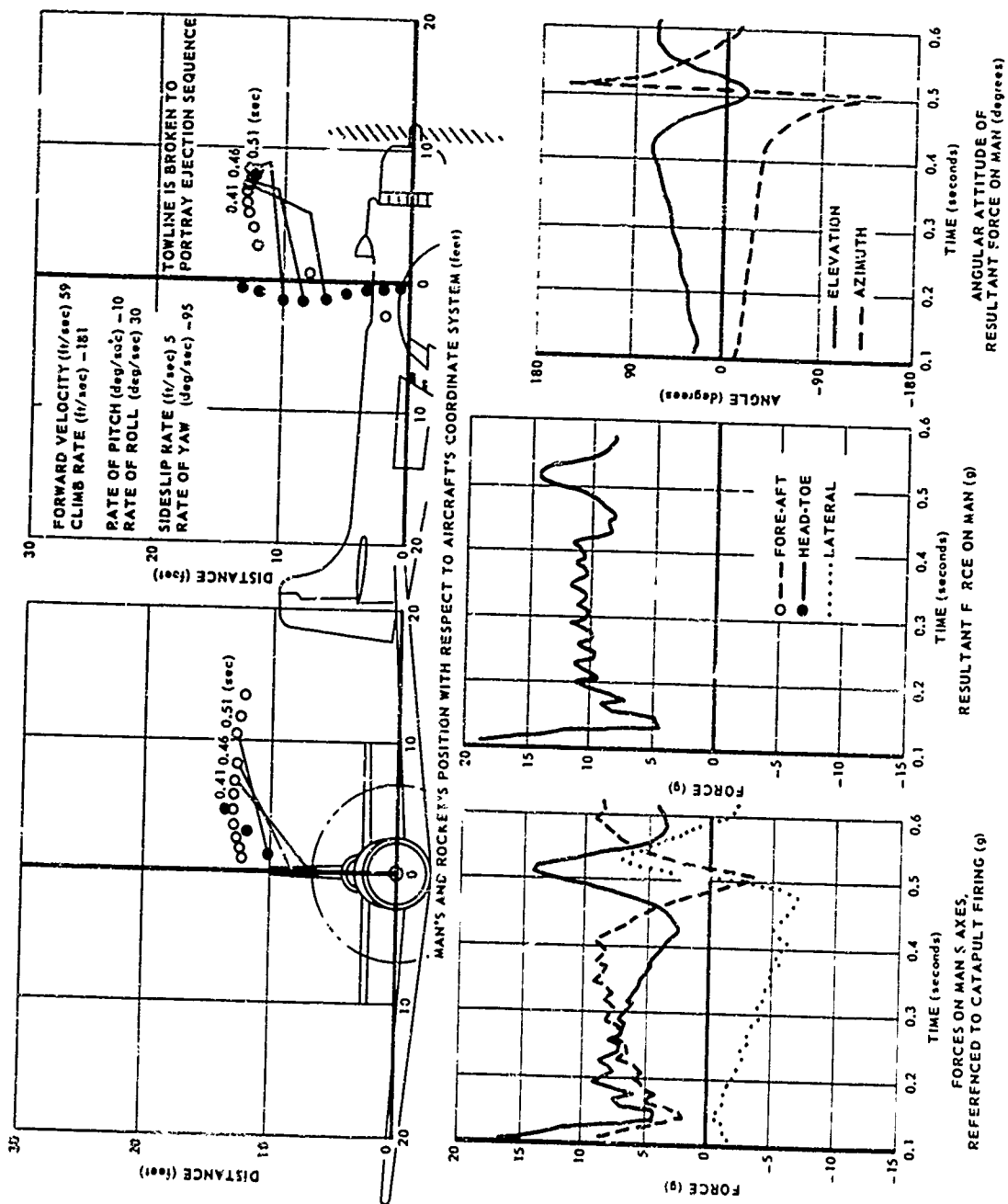


Fig- 40 Simulation Results, Three-Dimensional Tractor Rocket Ejection Studies, Condition 10b (Rocket Catapulted 27° ahead of Vertical)

REFERENCES

1. Naval Air Systems Command Letter RAAE-2312/389:FCG, 15 April 1966.
2. NATC Report No. FT-020R-65, 8 October 1965.
3. "Summary of a Preliminary Feasibility Study of a Tractor Rocket Aircrew Escape System," APL/JHU TG-676, June 1965.
4. "Data for Simulation of Tractor Rocket Escape System," Stanley Aviation Document No. 1542, 25 August 1966.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D		
<small>(Security classification of R&D, body of abstract and indexing annotation must be entered when the overall report is classified.)</small>		
1. ORIGINATING ACTIVITY (Corporate author) The Johns Hopkins Univ., Applied Physics Lab. 8621 Georgia Avenue Silver Spring, Maryland		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP
3. REPORT TITLE Aircraft Tractor - Rocket Escape Systems - Six-Degree-of-Freedom Digital Simulation. Final Report (U)		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report, with enclosures giving conditions investigated and results obtained.		
5. AUTHOR(S) (Last name, first name, initial) Bader, Frank and Coleman, Dean R.		
6. REPORT DATE February 1967	7a. TOTAL NO OF PAGES 67	7b. NO OF REFS 4
8a. CONTRACT OR GRANT NO. NOx 62-0604-C	9a. ORIGINATOR'S REPORT NUMBER(S) TG-864	
b. PROJECT NO. c. d.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10. AVAILABILITY/LIMITATION NOTICES Distribution of this document is unlimited.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Air Systems Command	
13. ABSTRACT <p>This report presents a six-degree-of-freedom digital simulation of an aircraft tractor rocket air crew escape system. The simulation described herein is a six-degree-of-freedom simulation in that each of the objects considered is free to translate linearly in three directions and rotate about these three linear axes. The simulation considers the motions of the four "objects" comprising the escape system: the airplane, the tractor rocket, the towline, and the crewman. The simulation begins at the instant the tractor rocket has been ejected from its catapult and terminates when the tractor rocket has burned out.</p> <p>The tractor rocket escape system was conceived by the Stanley Aircraft Corporation, for military aircraft which currently have no ejection systems for the air crew. (U)</p>		

UNCLASSIFIED
Security Classification

14.

KEY WORDS

Tractor Rocket
Six-Degree-of-Freedom Simulation
"Yankee" Escape System
Ejection Dynamics
Rocket Escape System
Stanley Aircraft Corporation

UNCLASSIFIED
Security Classification